Forecasting the Onset of Damaging Winds Associated with a Squall Line/Bow Echo Using the Mid-Altitude Radial Convergence (MARC) Signature
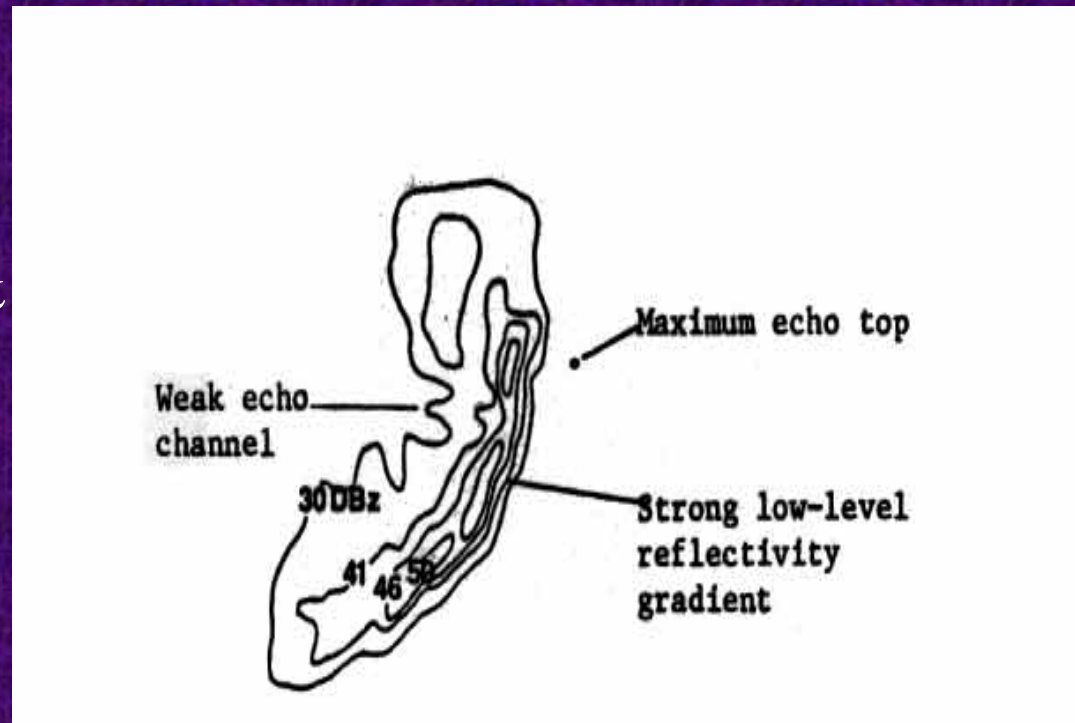
By

Gary K. Schmocker
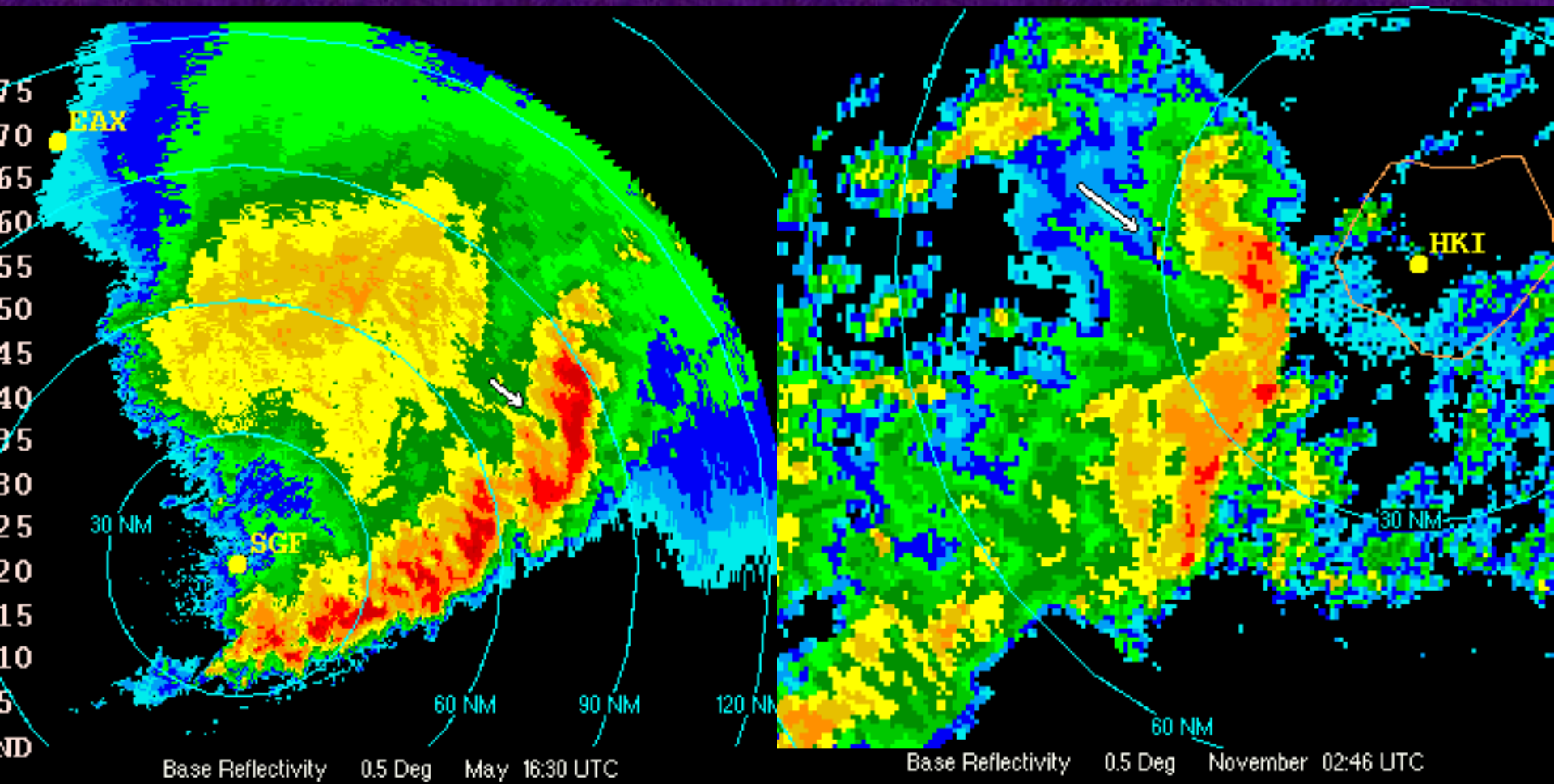
Ron W. Przybylinski

Introduction – Radar Based Signatures of Damaging Winds

- <u>Reflectivity Characteristics of a "distinctive" bow echo</u> (Fujita, Przybylinski & Gery):

- Bowing of line echo

- WECs or RINs

- Strong low-level reflectivity gradient
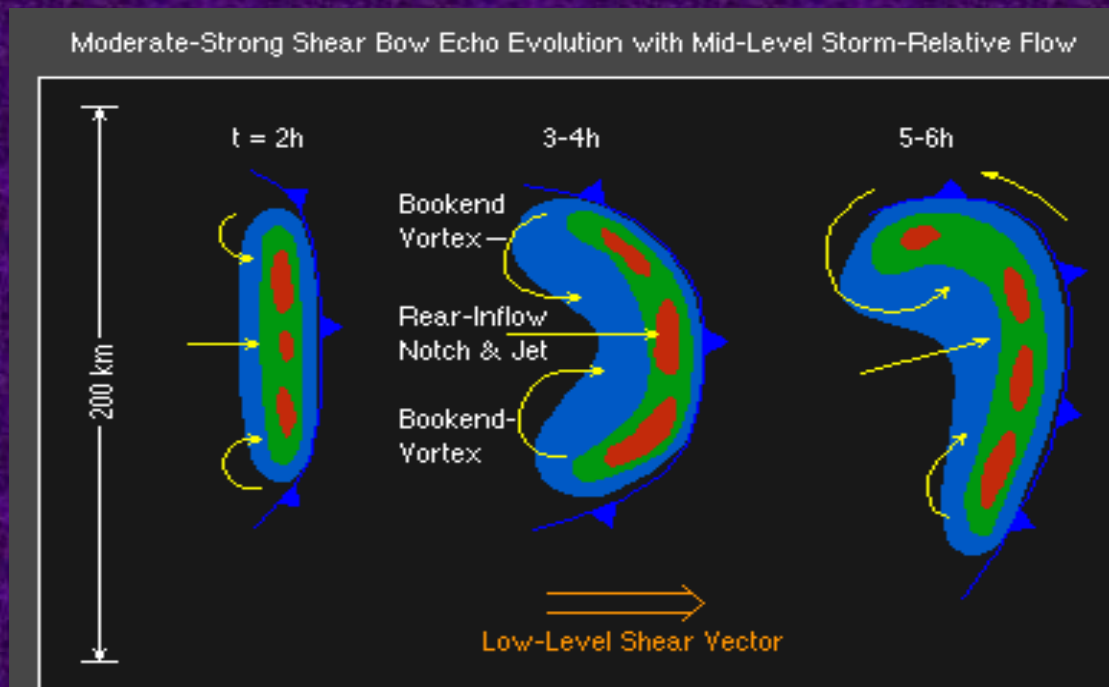
- Displaced max echo top

Two Examples of Bow Echoes with Strong Low-Level Reflectivity Gradients and Pronounced RINs

Introduction - Doppler Radar Based Signatures of Damaging Winds

- High VIL values (better correlation to heavy rain/hail)

- Base Velocity >= 50kts at lowest elevation (limited range)

- Identification of vortices – strong circs. along a convective line can enhance low–mid level winds (RIJ)
  - strongest wind damage often observed just south of the path of a cyclonic circ. (convective line typically accelerates and/or "bows out" south of a strong cyclonic circ.)

Moderate-Strong Shear Bow Echo Evolution with Mid-Level Storm-Relative Flow

t = 2h

3-4h

5-6h

200 km

Bookend Vortex

Rear-Inflow Notch & Jet

Bookend-Vortex

Low-Level Shear Vector

Damaging Wind Precursors Identified from Microburst Studies on Pulse Type Storms (Eilts et al. -DDPDA)

- Rapidly descending reflectivity core

- Initial core development at a higher height than surrounding storms

- Strong mid-altitude radial convergence (>22 m/s) associated with damaging winds in isolated pulse type storms
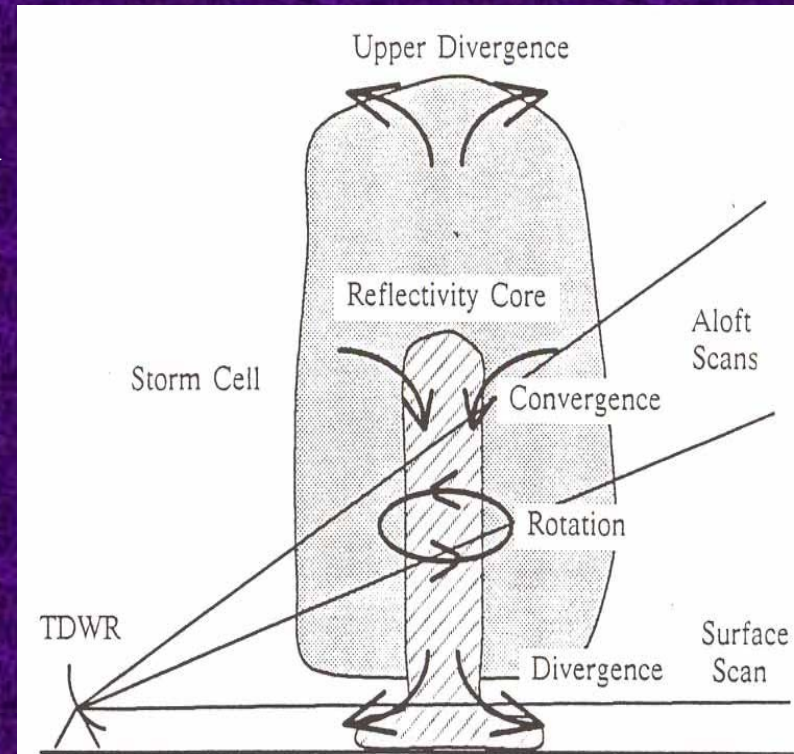
# Convergent Signatures in Organized Convection - Supercells

- Deep Convergence Zone (DCZ) identified in supercells (Lemon et al.) at the interface of the updraft/downdraft currents
  - narrow zone of intense convergence and shear with an average depth of 10 km
  - damaging winds often occur along or just behind DCZ with mesocyclones & gust front tornadoes along it
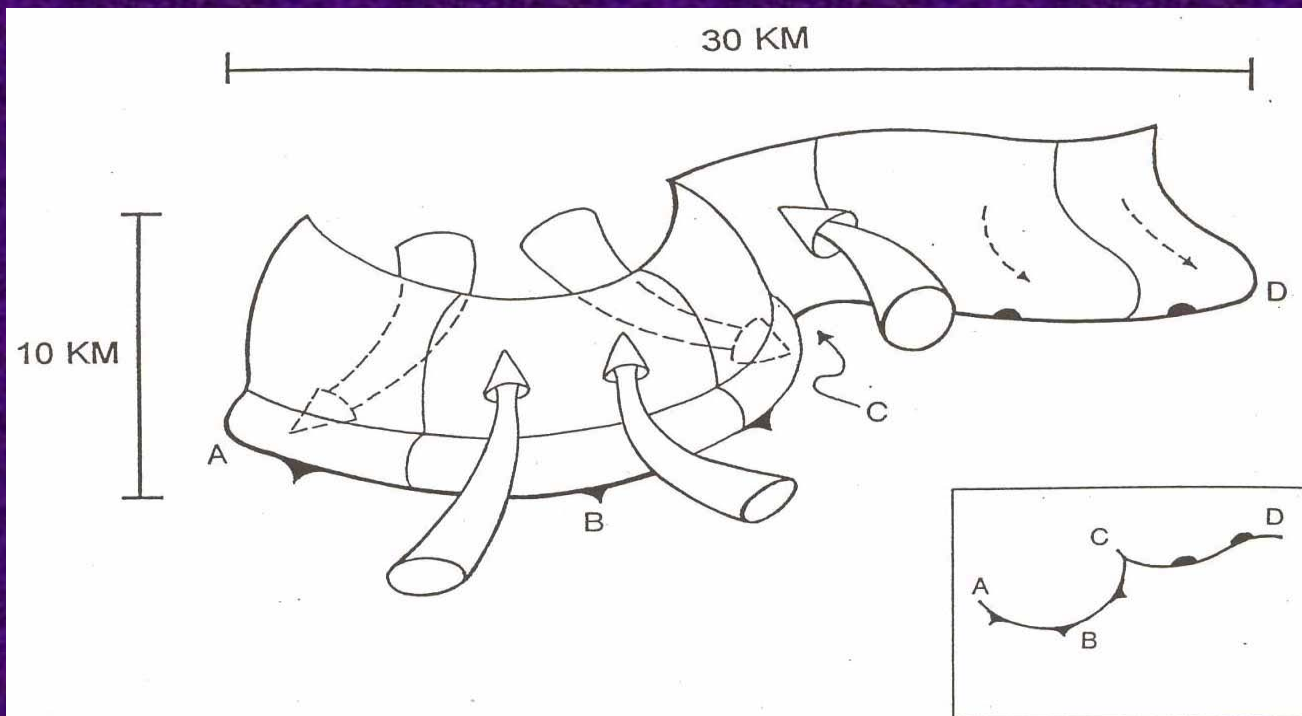
Convergent Signatures in Squall Line/Bow Echoes?
But first a review of squall line mesoscale airflow structures

STORM CONCEPTUAL MODEL - MESOSCALE AIRFLOW STRUCTURE OF A LARGE - MATURE MCS
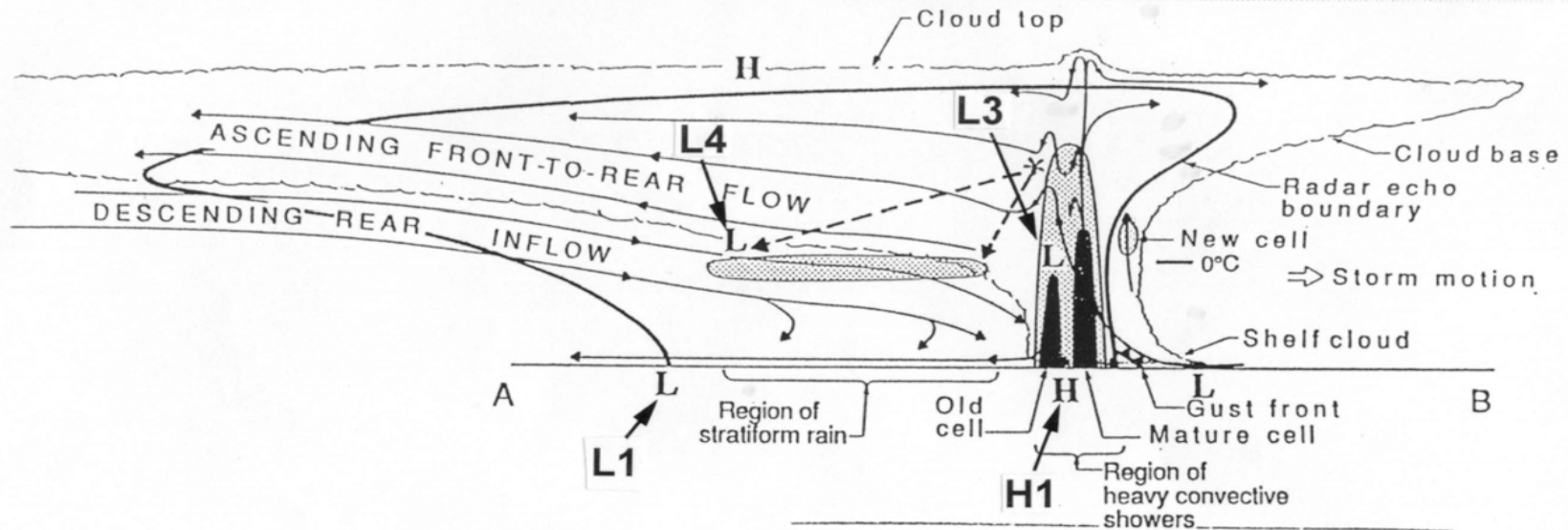
Development of RIJ attributed to mid-level, mesoscale areas of low pressure (L3 & L4; Smull & Houze,1987)

L3: Hydrostatically induced negative pressure perturbations under upshear tilted warm convective updrafts (& above evaporatively cooled downdrafts)

L4: Midlevel mesoscale low in the stratiform region

Dual Doppler Analysis of a Northern Plains Squall Line (Klimowski 1994)

- Observations of the mesoscale rear inflow jet (RIJ):
-Rear inflow was initiated near the high reflectivity cores of the squall line & largely elevated, increasing in magnitude & expanding rearward with time (RIJ mean height near 4 km MSL)
-Maximum values of the rear inflow were initially located near the high reflectivity cores at the front of the system
-The rear inflow was not homogeneous along the length of the squall line (variability in elevation & several local maxima of rear inflow along line)
-Rear inflow was stronger where the trailing stratiform precipitation region formed
-Slight positive correlation between the development of the rear inflow & the development of the front-to-rear (FTR) flow (where RIJ was strongest, FTR usually maximized)
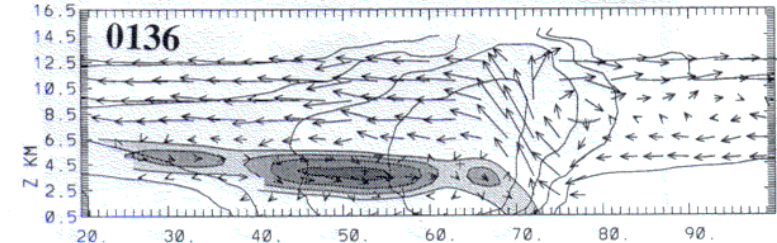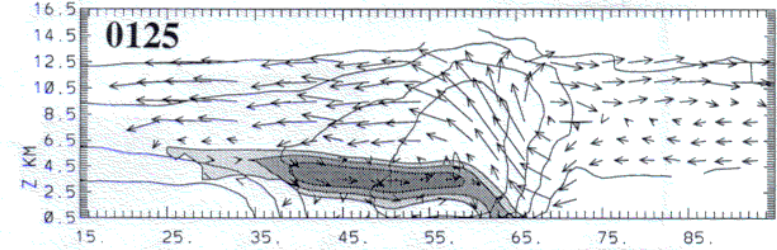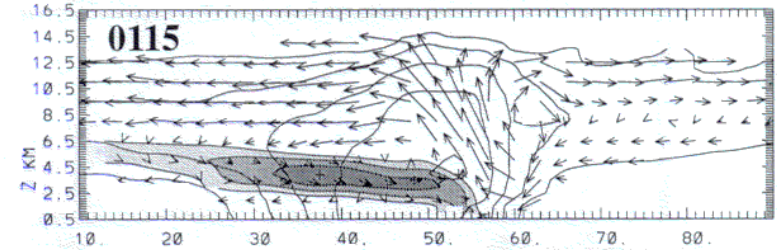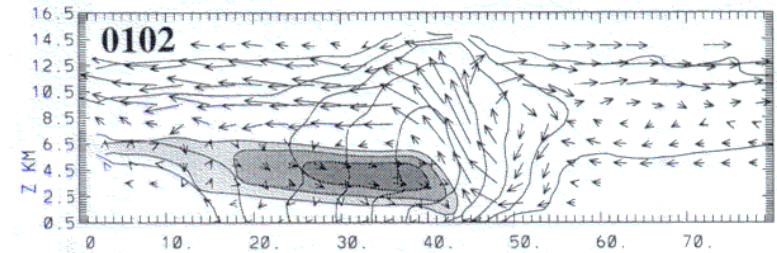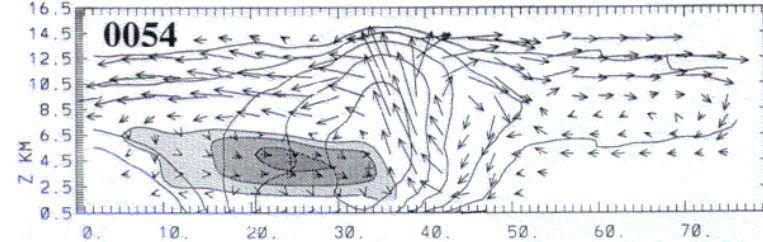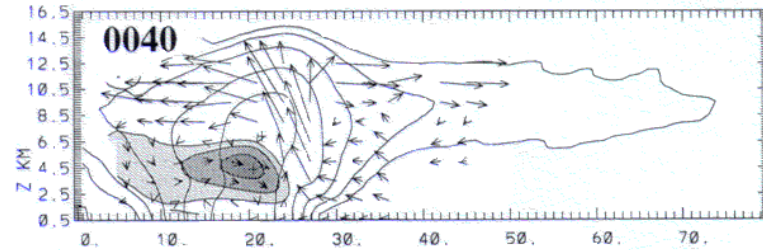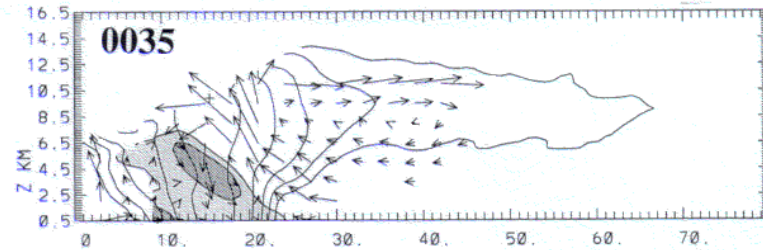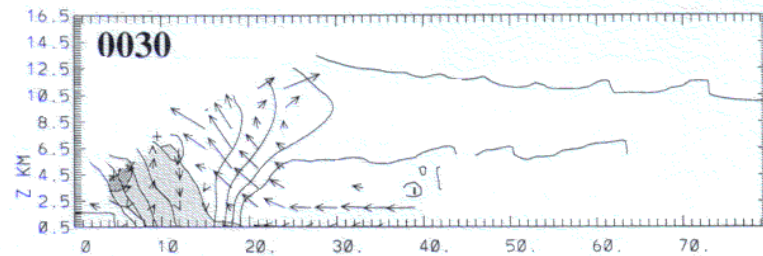
Reflectivity / velocity cross-sections perpendicular to squall line. Reflectivity contours are solid. Shaded region represents the evolution of the mesoscale rear inflow jet (Klimowski 1994).

Convergent Signatures in Organized Convection - Squall Lines/Bow Echoes

- Przybylinski et al. 1995 noted strong mid-altitude radial convergence (MARC) along the forward flank of convective lines before they began to "bow out"

- We are using the WSR-88D to survey a component of the squall line's sloping updraft/downdraft currents along the forward flank of the MCS during the intensifying stage:
  - region of strong outbound velocities signifies a component of the storm's updraft current and FTR flow (with respect to approaching storm west or upstream of radar)
  - region of strong inbound velocities depicts the storm's convective scale downdrafts & origins of the mesoscale RIJ

Mid-Altitude Radial Convergence (MARC) in a Mature MCS
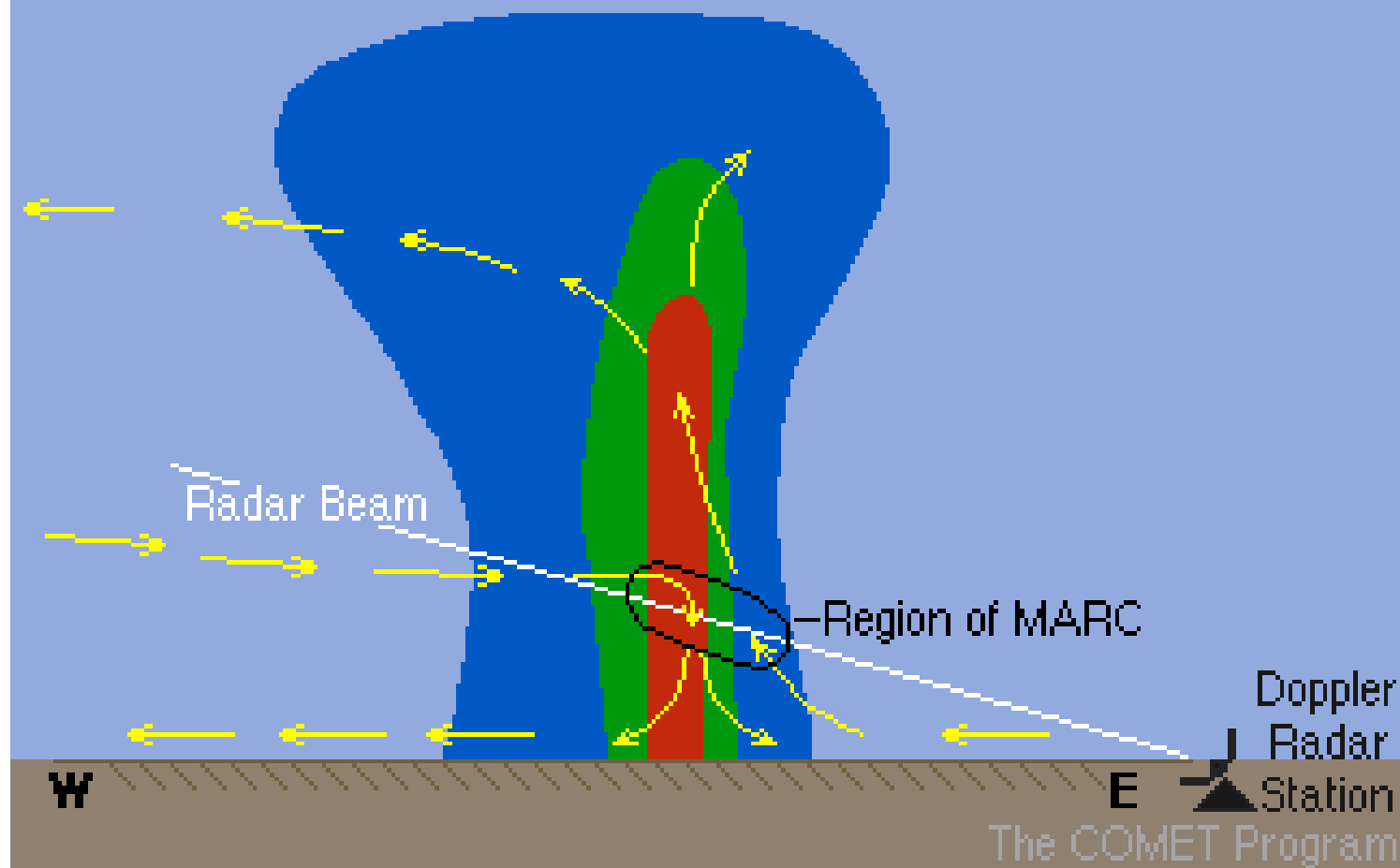
MARC Dynamics (cont.)

- Persistent areas of strong radial convergence (enhanced convergent velocity differentials) within the larger zone of convergence along the forward flank of the convective line appears to be linked to the greatest degree of wind damage.

- These persistent areas of strong radial convergence (the MARC velocity signature) are usually located in or just downwind of the high reflectivity cores along the leading edge of the line.

- These enhanced areas of convergence are usually < 15 km in length & < 7 km in width. A strong velocity gradient between the inbound and outbound maxima (nearly gate to gate) yields the strongest actual convergence.

An example of MARC in a developing line echo.
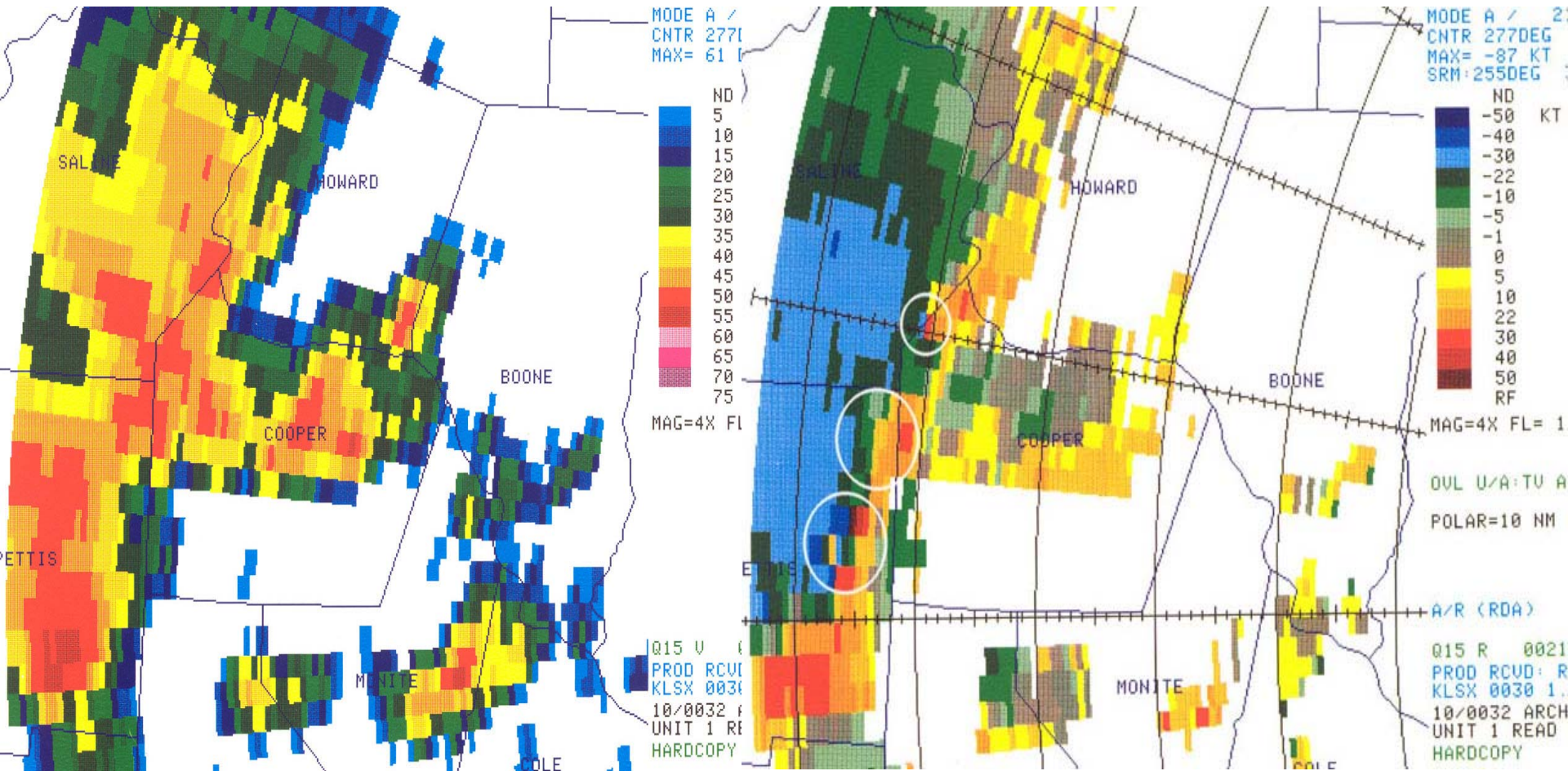
White circles enclose 3 MARC velocity signatures - enhanced spots of convergence within an elongated zone of convergence along the forward flank of the linear convective system over central MO (west of radar site KLSX)

More MARC Dynamics

- Once radial velocity differentials reach 25 m/s or greater (actual convergence values of 2.5×10^{-2} to 5.6×10^{-3} s^{-1}), the potential for severe straight line winds increase.
  Radial Convergent Velocity Difference = |V(inbound)| + |V(outbound)|
  Actual Convergence = |V(inbound)| + |V(outbound)| / distance between convergent isodops along radial

- Convective-scale vortices (tornadic as well as non-tornadic) often form in the zone or interface between the two drafts (mainly on the updraft side) where cyclonic or negative horizontal vorticity is strong.
  - a cyclonic circ. has developed on the northern end of a MARC signature in several of our cases
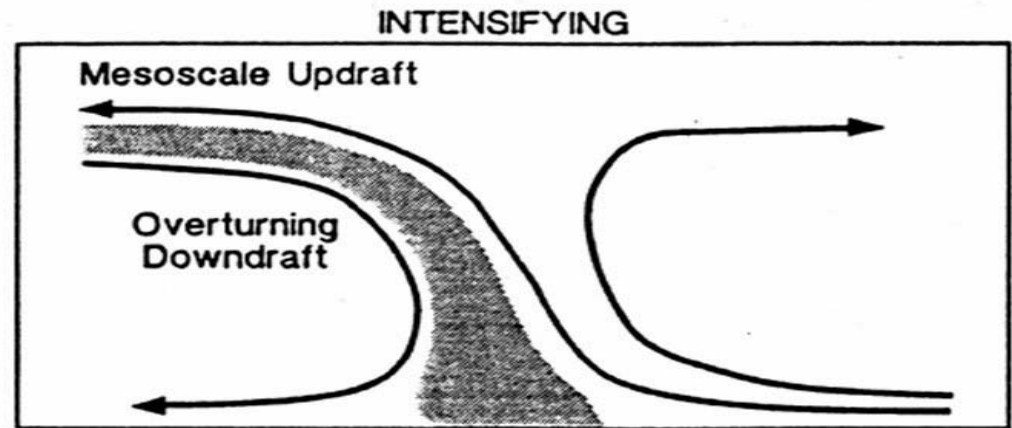
Schematic diagram of the 'Intensifying Stage' of squall line flow features adapted from Thorpe et al. (1982). Vorticity zone is shaded region.

Reflectivity Characteristics & the MARC Signature

The MARC velocity signature has been observed more frequently with a nearly solid linear convective segment (left) compared to discrete convective cells along the southern flank of an asymmetric MCS (right).
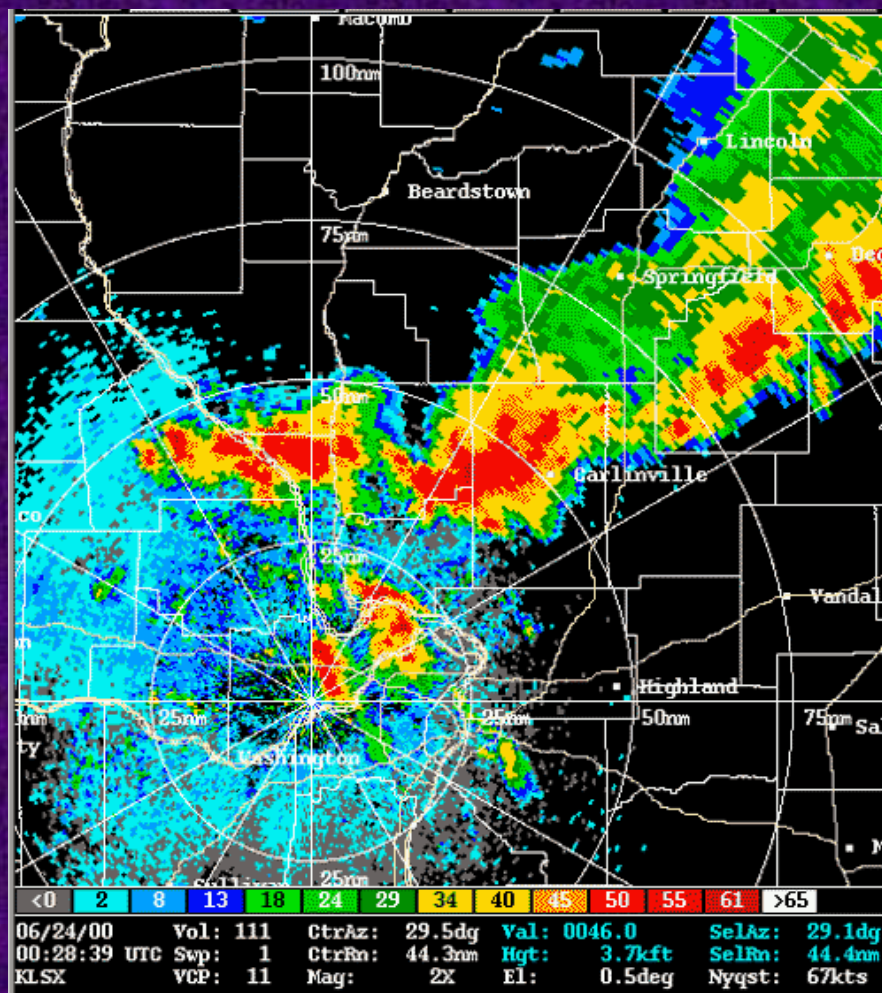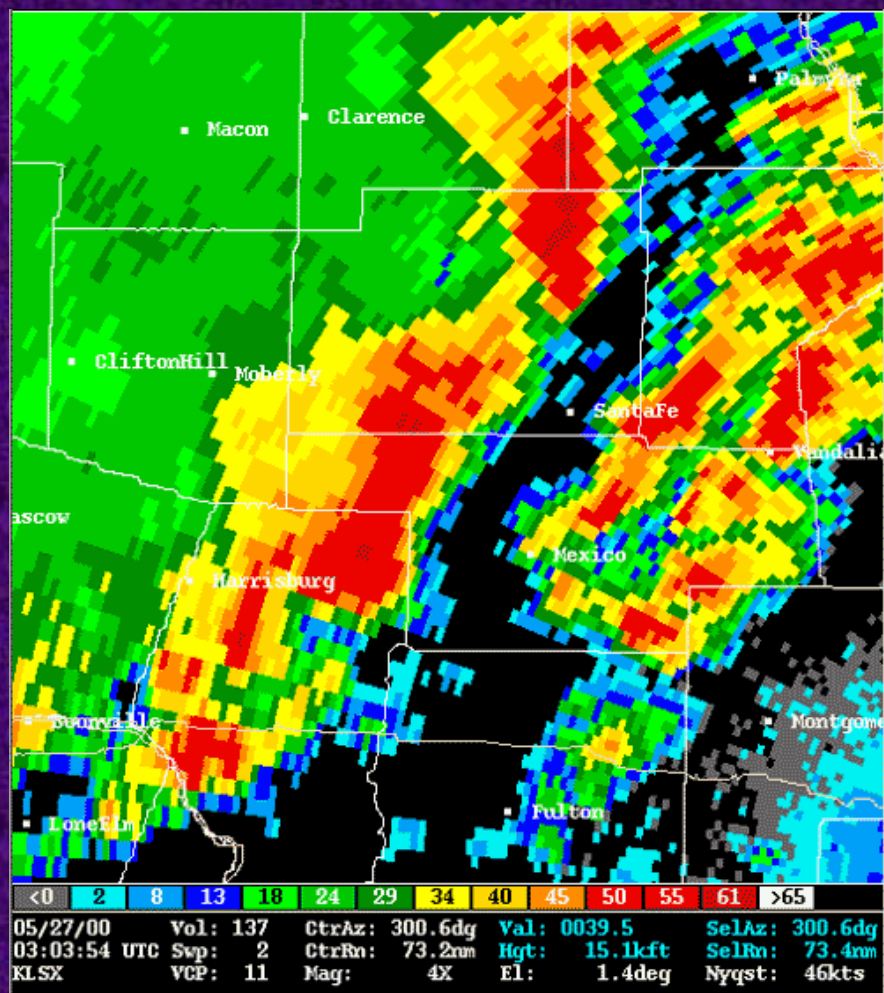
Case Sample & MARC Characteristics
16 warm season (May-September) MCS cases studied so far

Cases (1992-2000)	Instability/Shear (0-3 km bulk shear)	Initial Hgt of Marc (km)	Strongest Mag (m/s) and Height of MARC (km)	Horizontal extent of Convergent area (km)	Vertical Extent of MARC (km) & Mean Hgt(km)	Lead Time (min)
9 afternoon/ evening	2200-5000 J/Kg 3458 J/Kg 10 -17 m/s 13.7 m/s	2.4 - 7.3 Km 4.7 Km	26 - 55 m/s 39.5 m/s 1.9 - 7.3 Km 4.6 Km	50 - 160 Km 83 Km	2.8 - 6 Km 4.4 Km 3.3 - 6.3 Km 4.7 Km	3 - 80 min 21 min
5 late night/ early morning	2006-4000 J/Kg 3150 J/Kg 11 - 20 m/s 16.4 m/s	3 - 5.2 Km 4.4 Km	27 - 45 m/s 34.6 m/s 2.4 - 6.6 Km 4.1 Km	35 -75 Km 50 Km	1.4 - 5.4 Km 3.5 Km 3.0 - 5.7 Km 4.4 Km	1 - 39 min 14.2 min
All 16 cases 9 afternoon/ evening 5 late night/ early morning 2 mid-late morning	2006-5000 J/Kg 3352 J/Kg 10 - 20 m/s 14.7 m/s	2.4 - 7.3 Km 4.5 Km	26 - 55 m/s 37.5 m/s 1.9 - 7.3 Km 4.3 Km	35 - 160 Km 75 Km	1.4 Km - 6 Km 4.0 Km 3.0 - 6.3 Km 4.6 Km	1 - 80 min 18.7 min

# Differences Between Afternoon/Evening & Nocturnal (Late Night/Early Morning) Cases

- Afternoon/evening cases have greater CAPE, but less 0-3 km shear.

- In nocturnal cases MARC is weaker, shallower, & found at a lower height.

- The horizontal extent of the overall convergent region along the forward flank of the convective line is also less in the nocturnal cases.

- The MARC signature has shown greater lead time in the afternoon/evening cases.
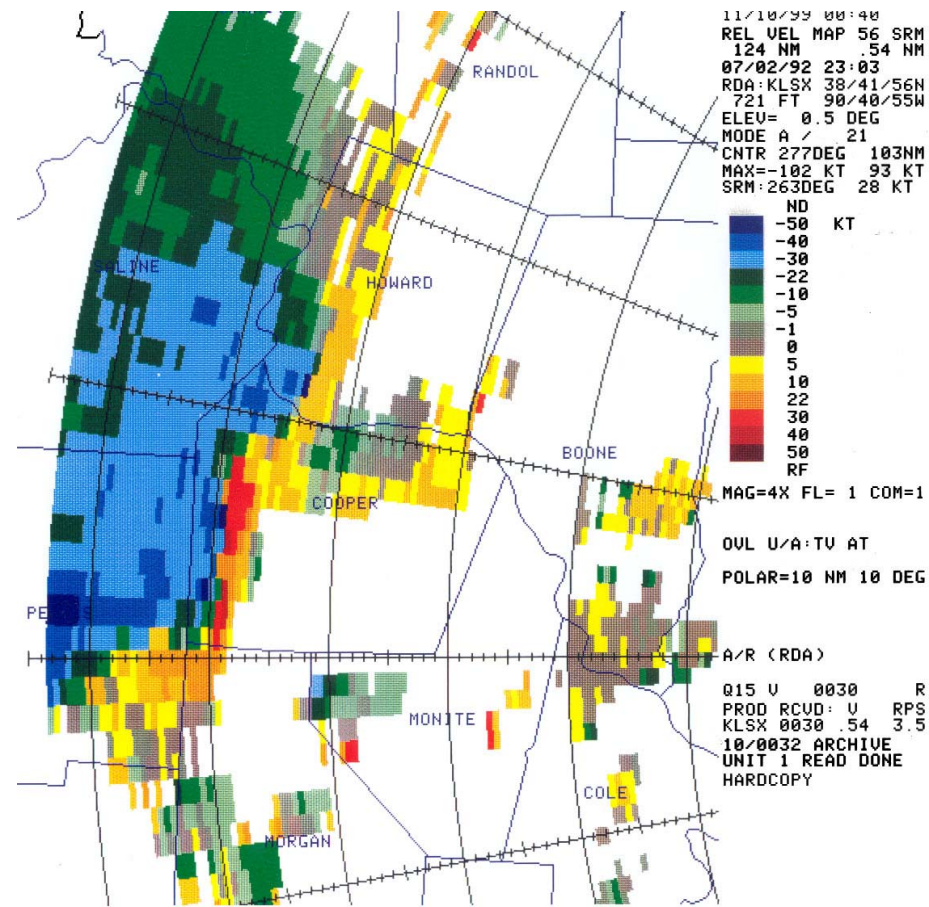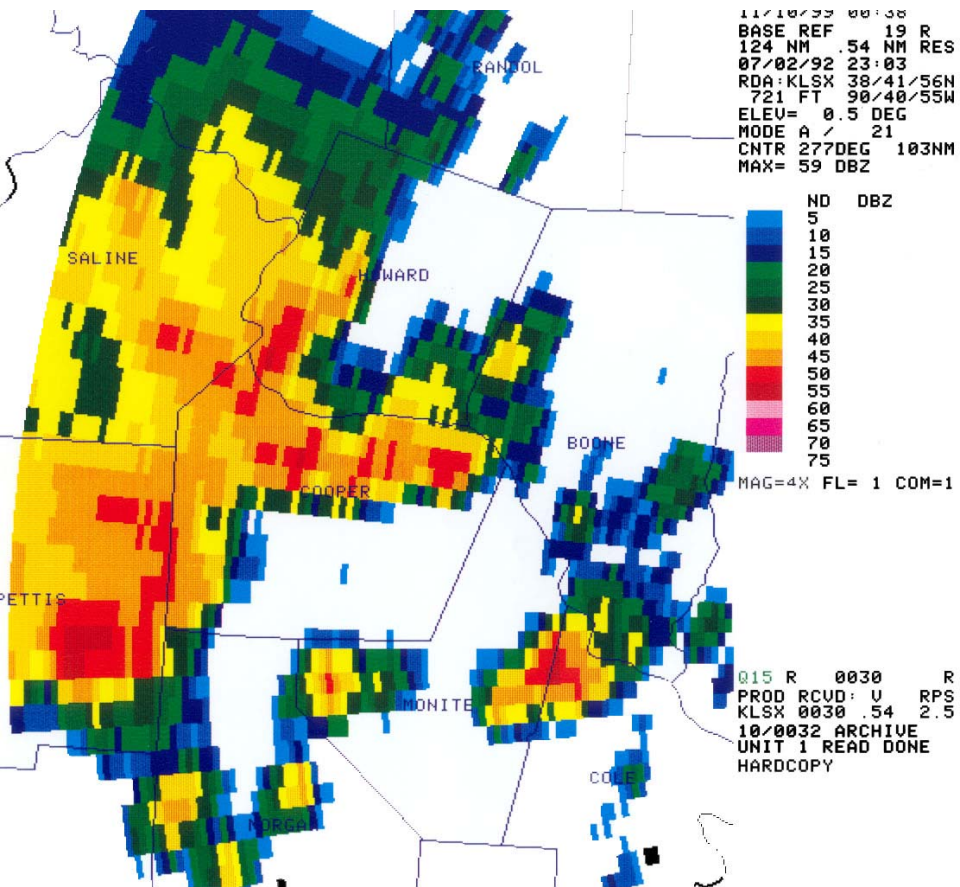
Case Example #1 – July 2, 1992
(high instability & moderate shear)
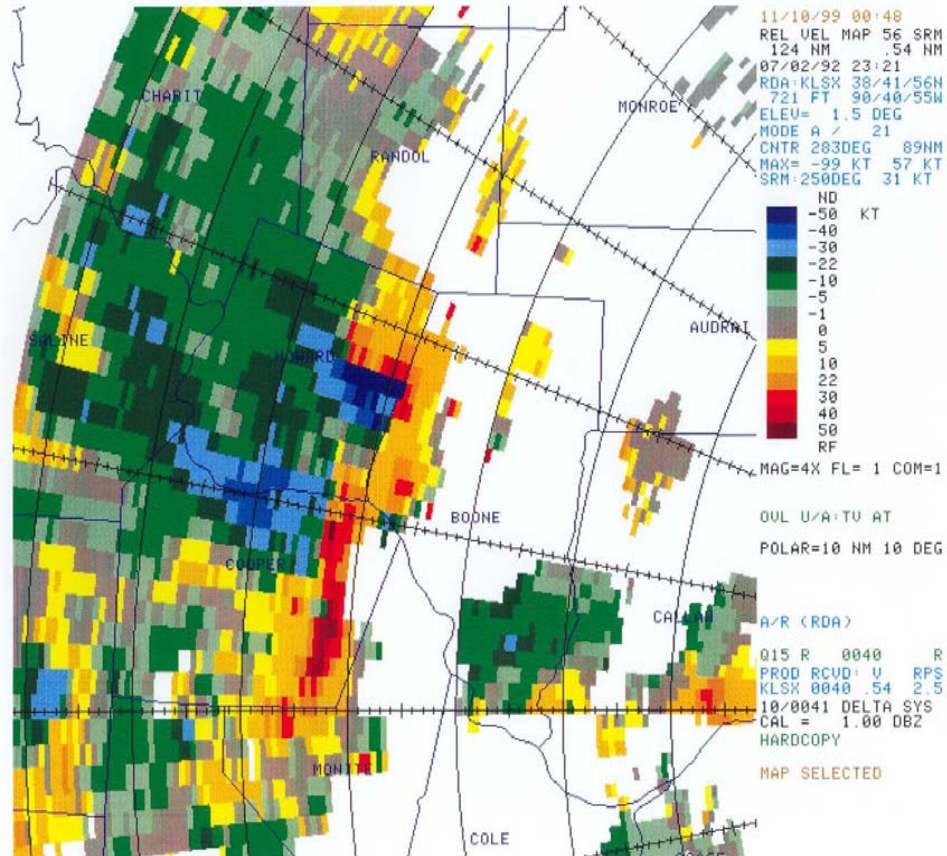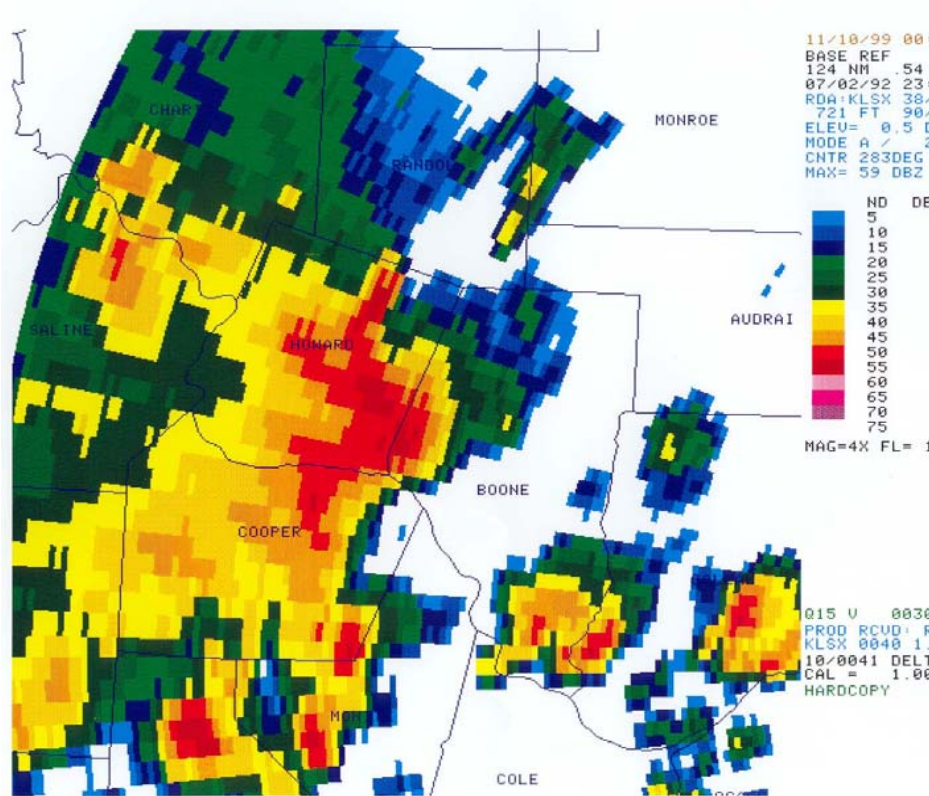## MARC tracks & initial wind damage reports (W)
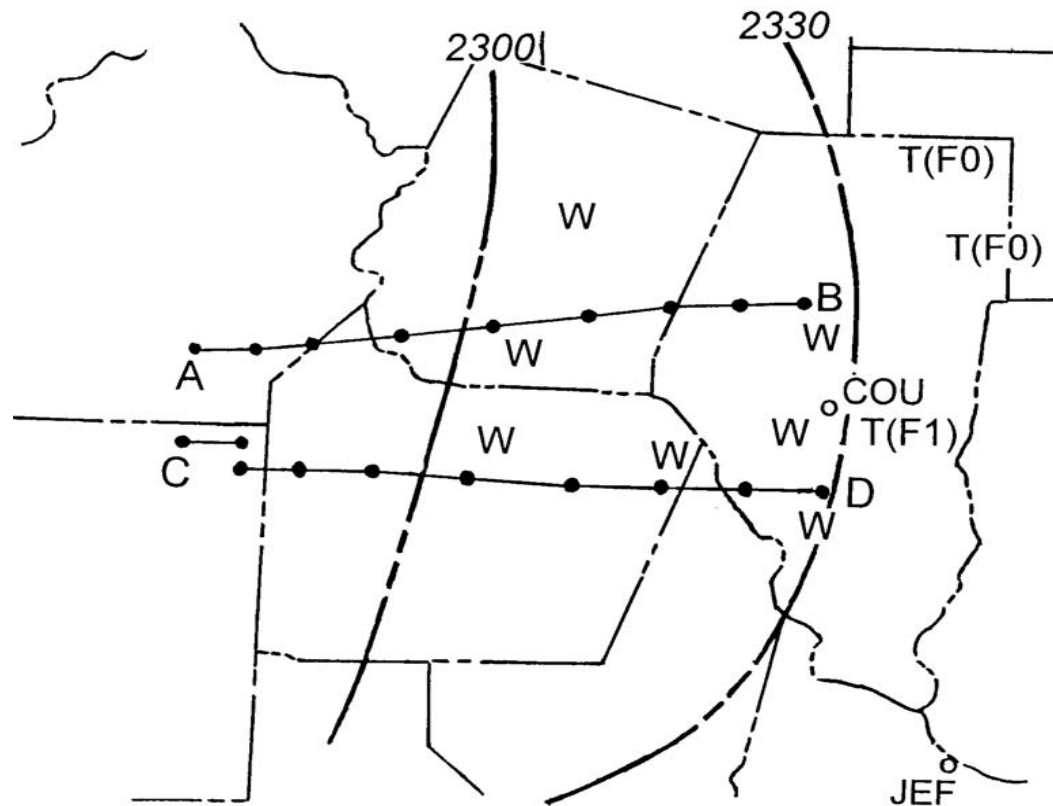
2303 UTC Reflectivity/SRM Velocity images at 0.5 ° - strong MARC signatures on the leading edge of developing line echo
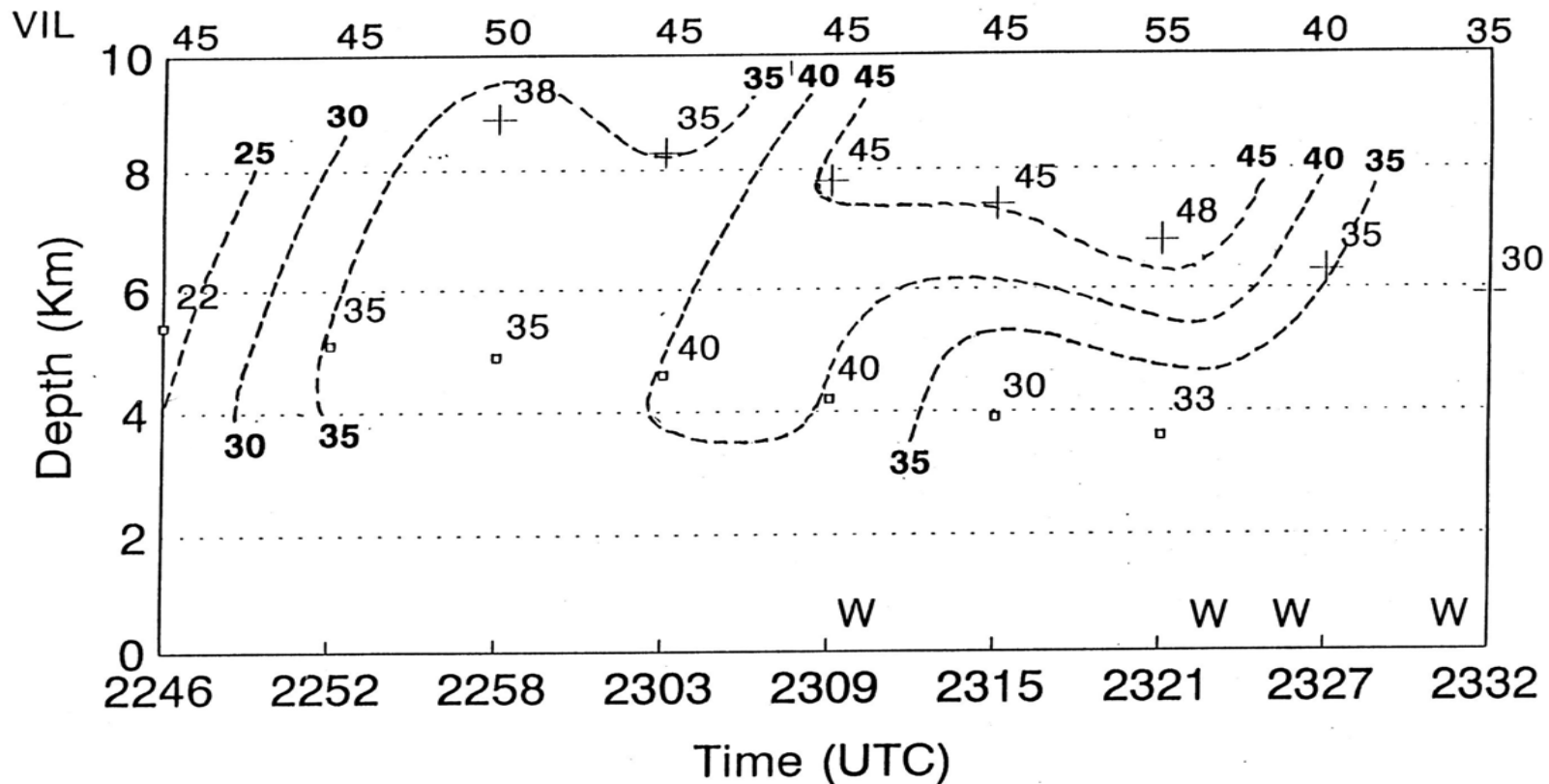
2321 UTC Reflectivity (0.5 °) & SRM velocity image (1.5 °) - bow echo has developed with 2 MARC signatures south of strong cyclonic vortex

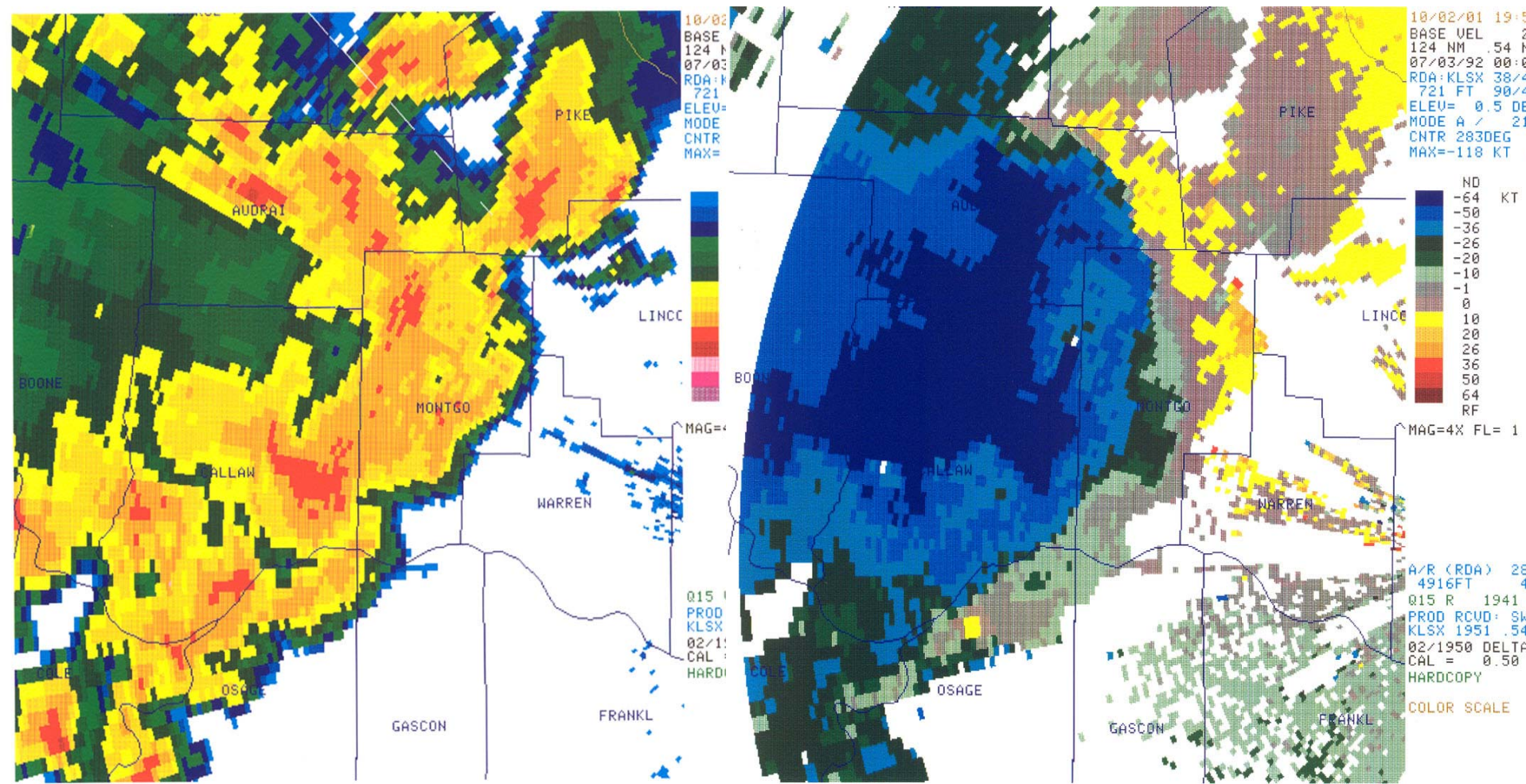# Time Height Section of Southern MARC (m/s) Signature (VIL is plotted on top while W denotes times of wind damage reports)
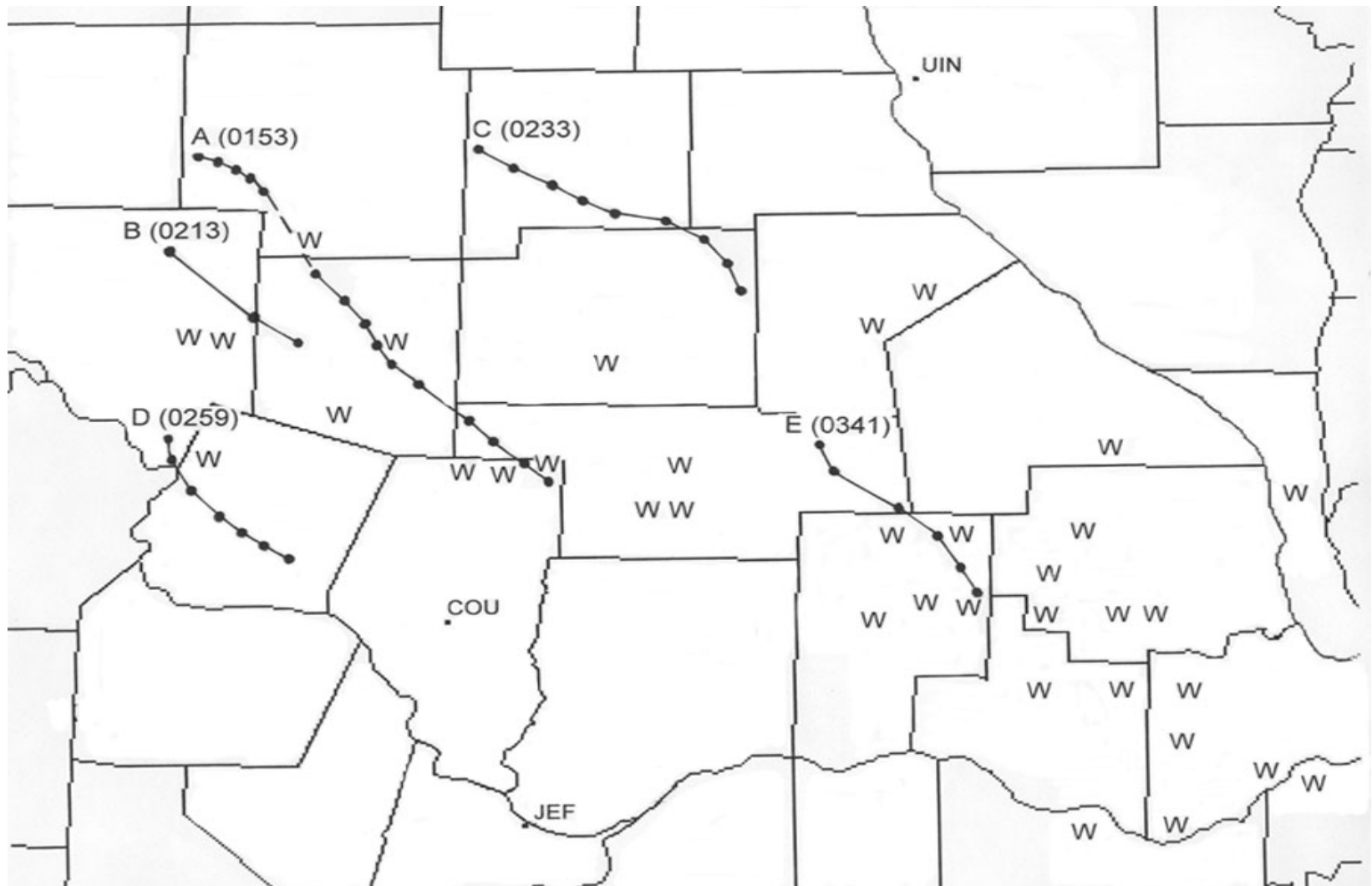

JULY 2, 1992

275 - 278° RADIAL

0007Z 0.5° reflectivity/base velocity images show a large, mature bow echo with a large area of >64 kt inbounds at 5-6 kft nw of KLSX
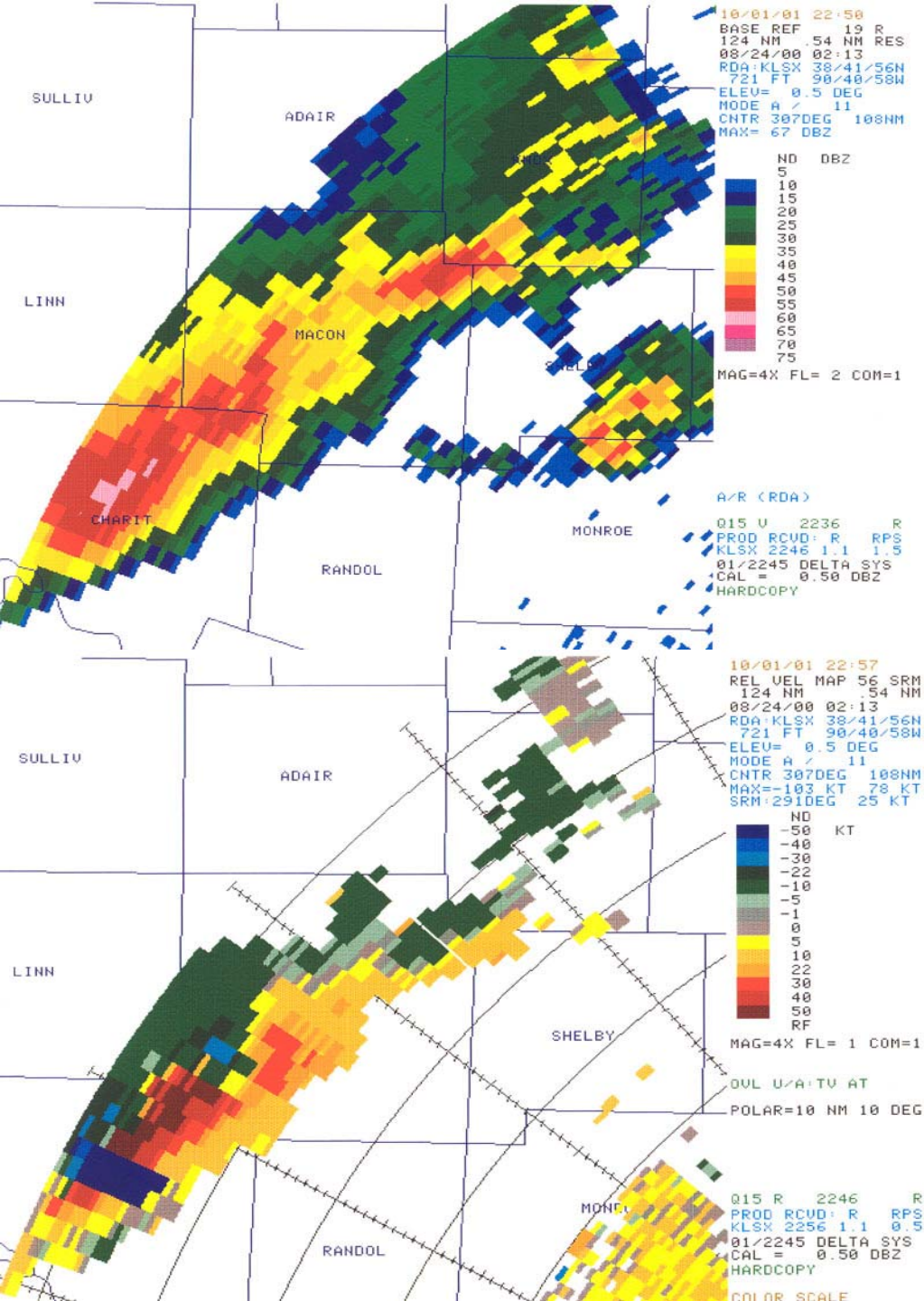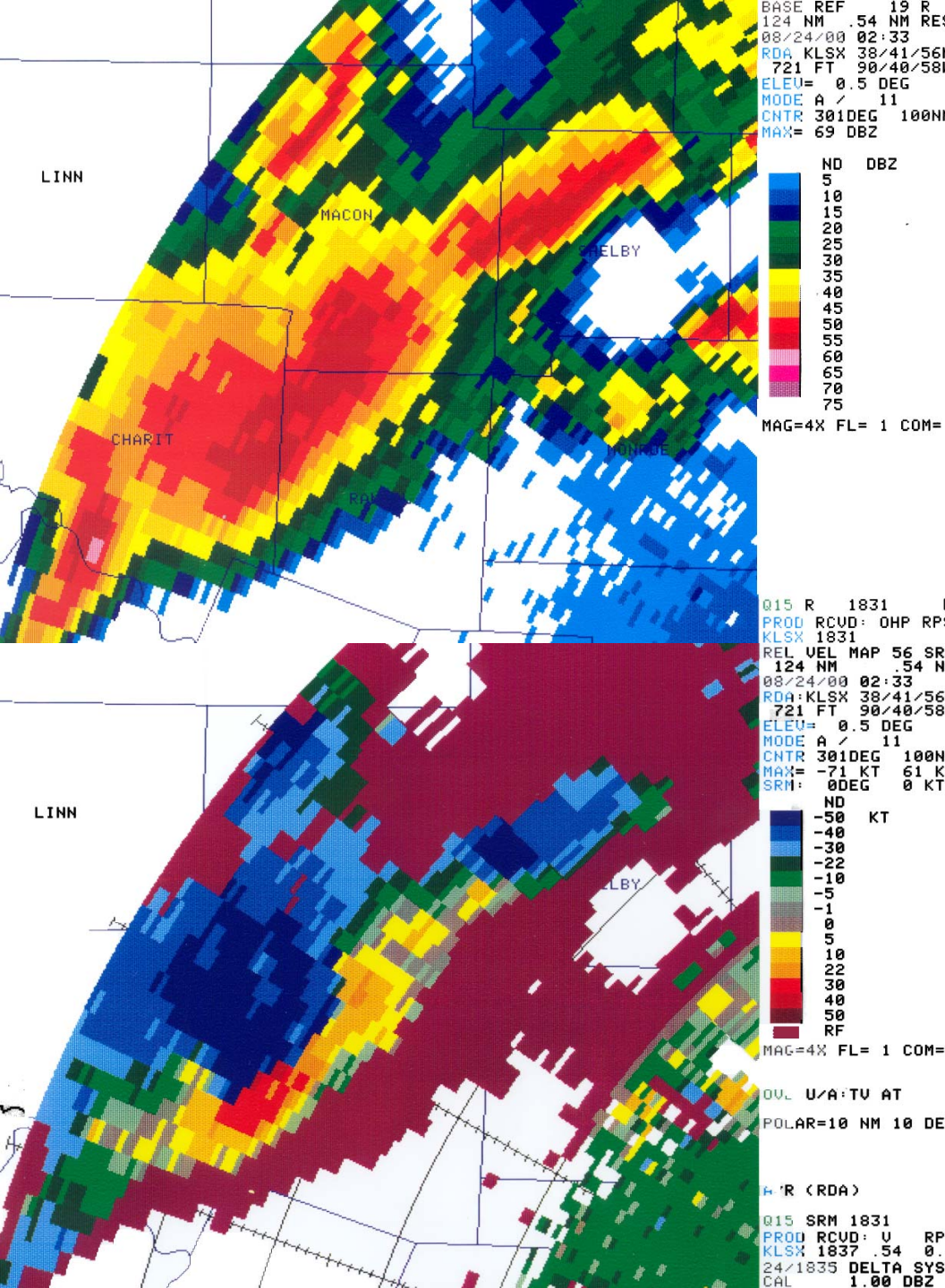
Case Example #2 - August 24, 2000
(high instability & weak shear)
MARC tracks & wind damage reports (W)
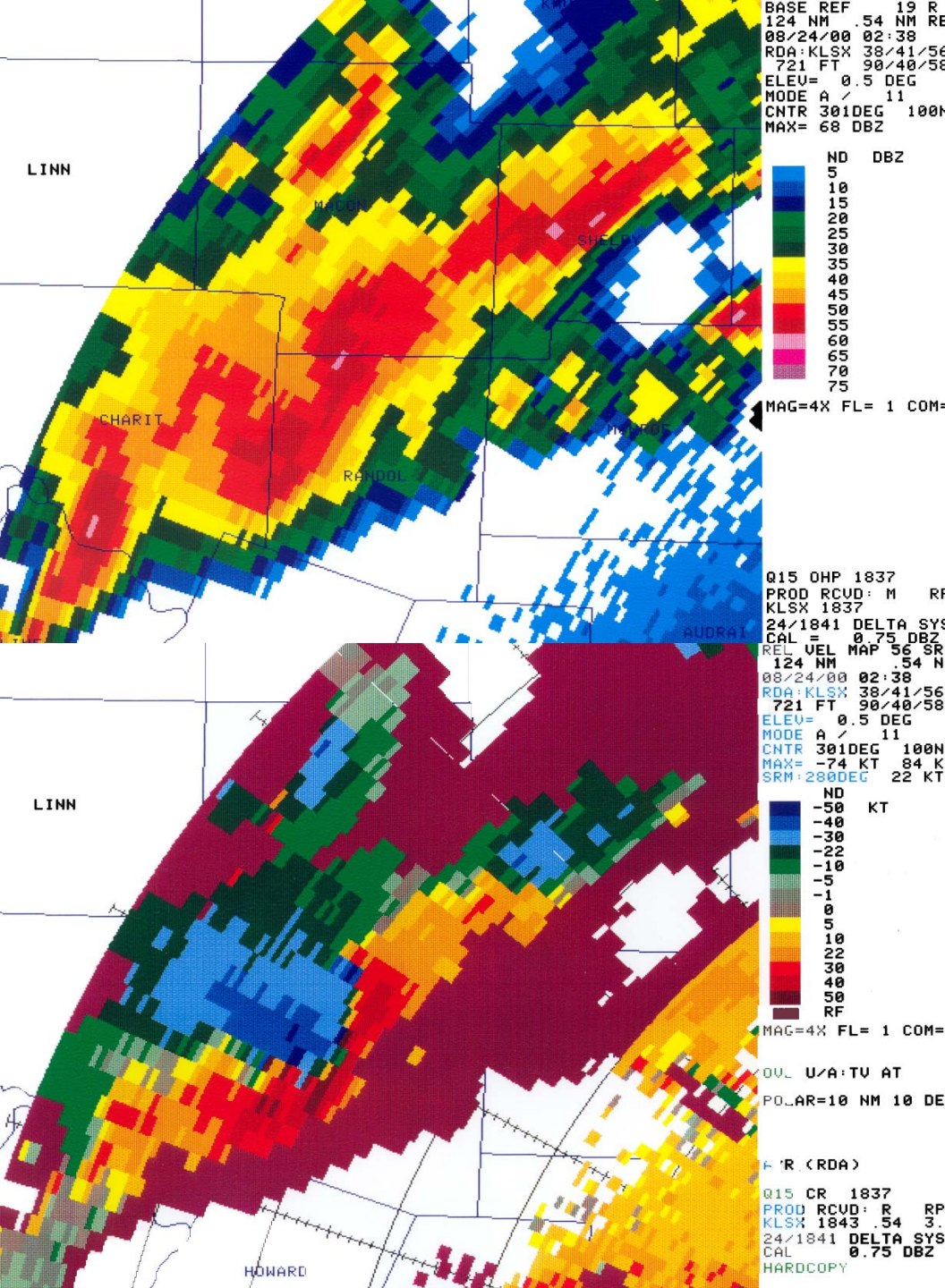
0.5° reflectivity & SRM velocity images at 0213Z over central MO showing 2 MARC signatures (A&B) in developing line segment

0.5 ° reflectivity & SRM velocity images at 0233Z over central MO display strengthening MARC signatures as RIJ intensifies

0.5 ° Reflectivity & SRM velocity images one volume scan later at 0238 Z – strong MARC noted between cyclonic & anticyclonic vortices.
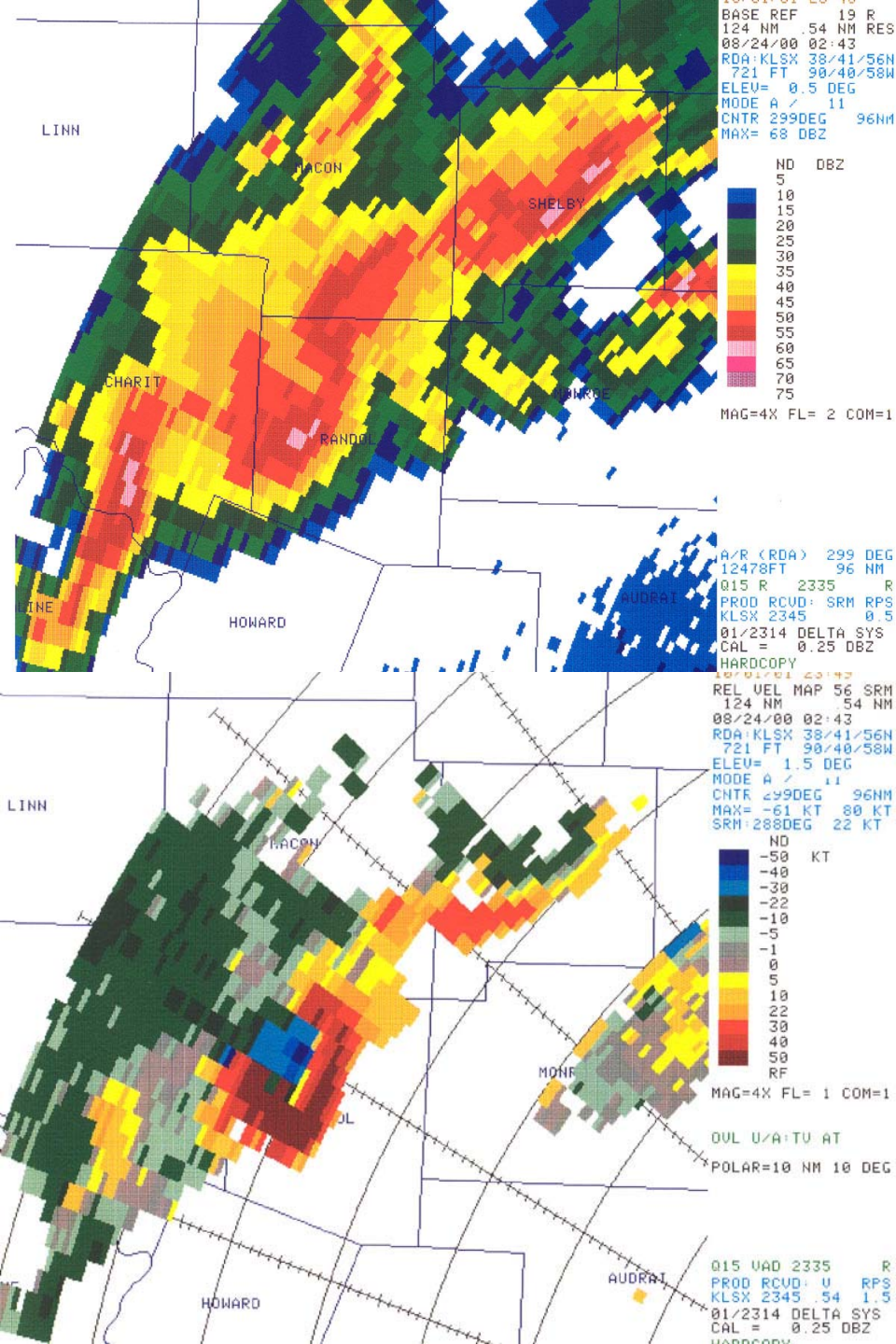
0.5° reflectivity and 1.5 ° SRM velocity images at 0243Z - RIN coincident with strong inbounds (RIJ)

24 August 2000: MARC - Trace A
Convergent Radial Velocity Differences (m/s)

Data from KLSX
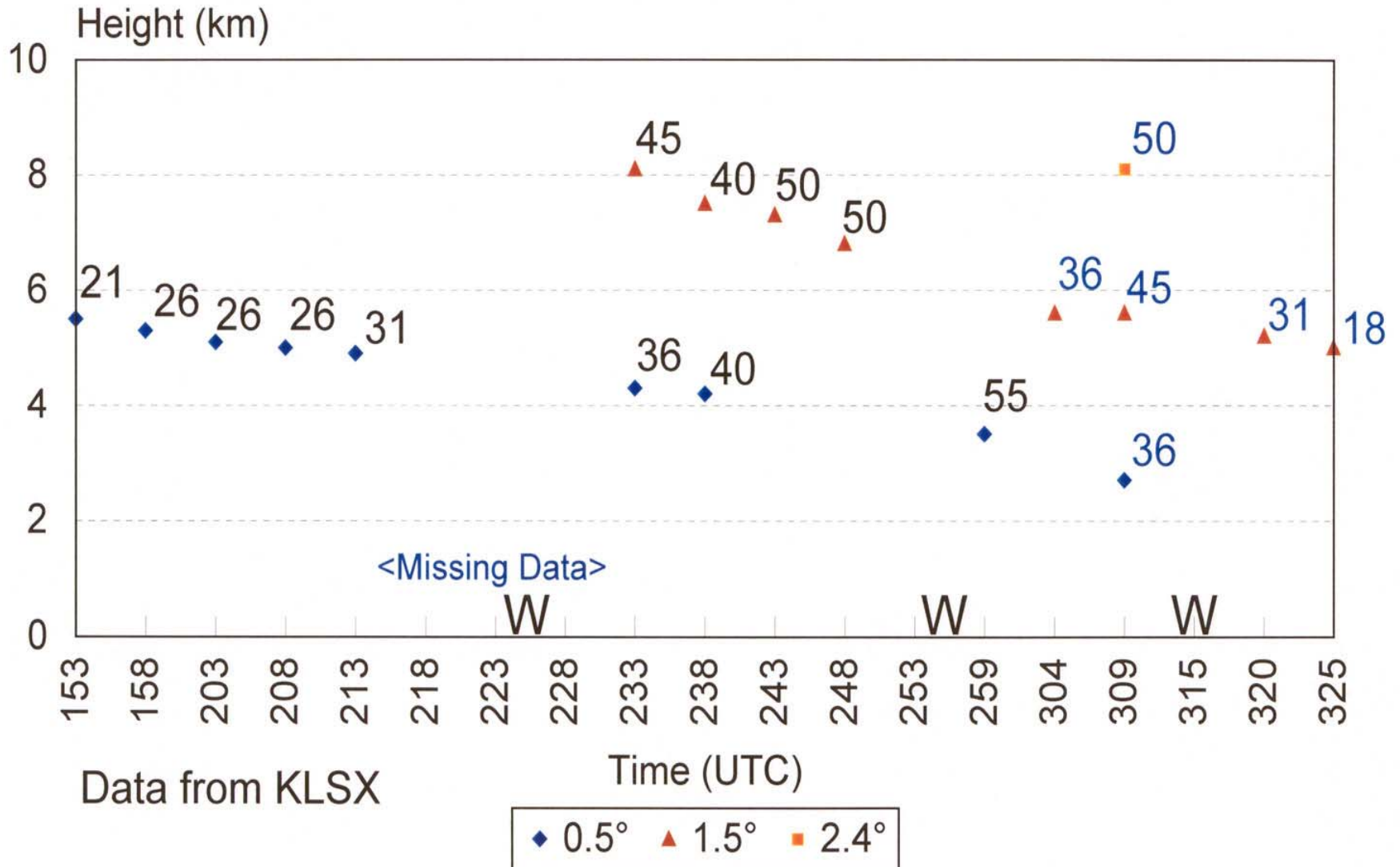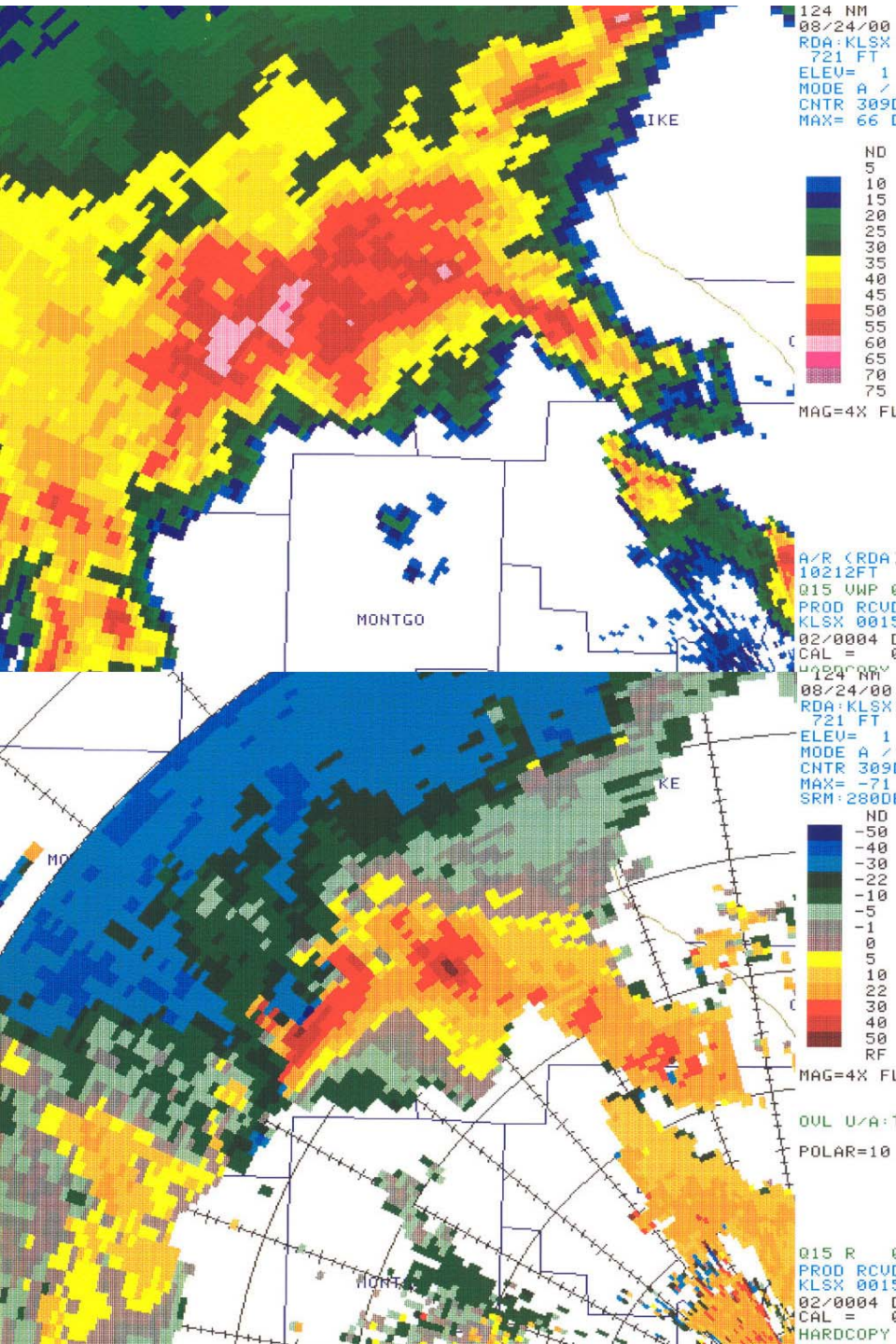
0341 UTC 1.5° reflectivity & SRM velocity images - new MARC Signature (E) rapidly develops just ahead of 60-65 DBZ cores in large convective cluster

24 August 2000: MARC - Trace E
Convergent Radial Velocity Differences (m/s)

Data from KLSX

Time (UTC)

Legend: ▲ 1.5° ■ 2.4° ◆ 3.4°
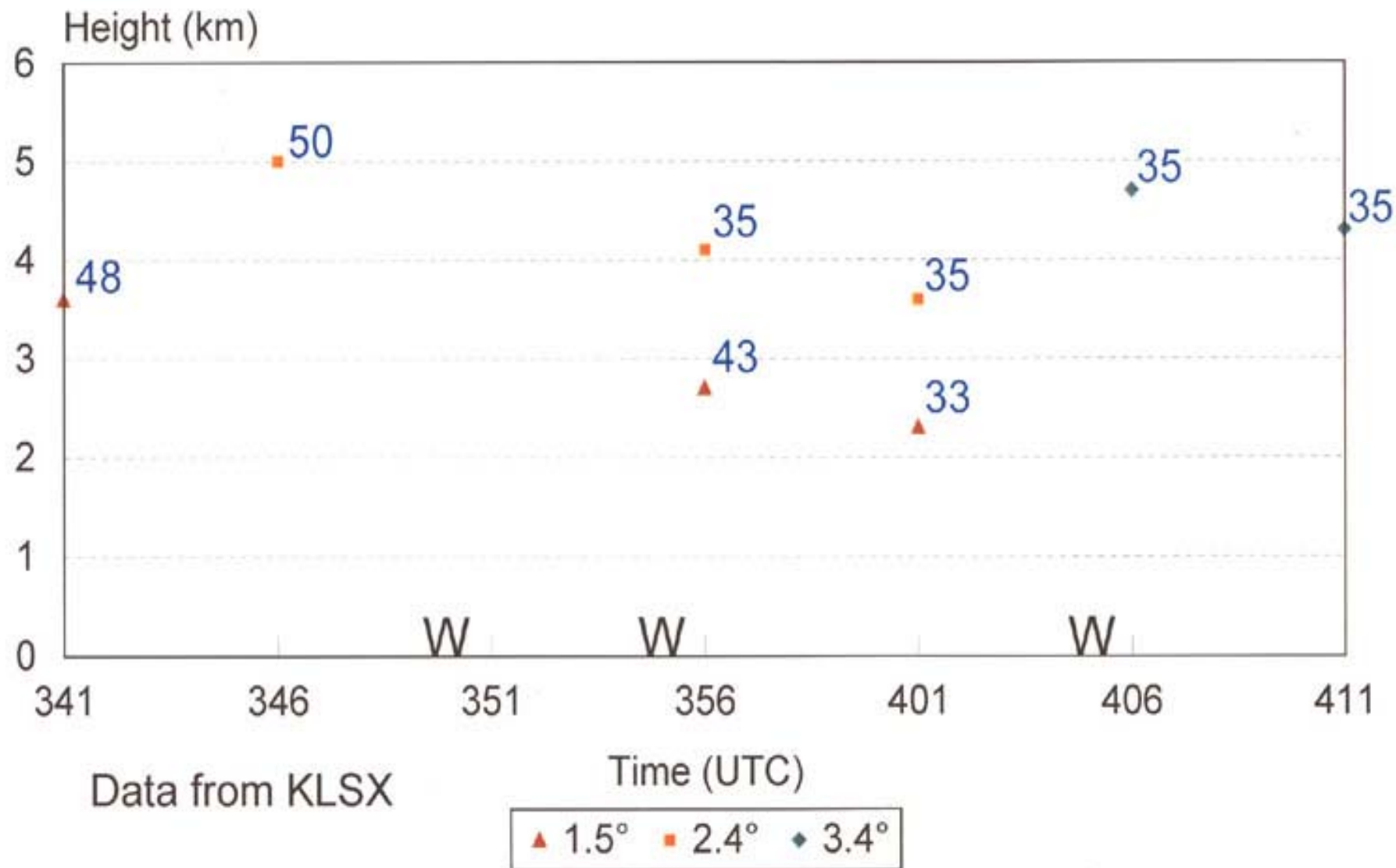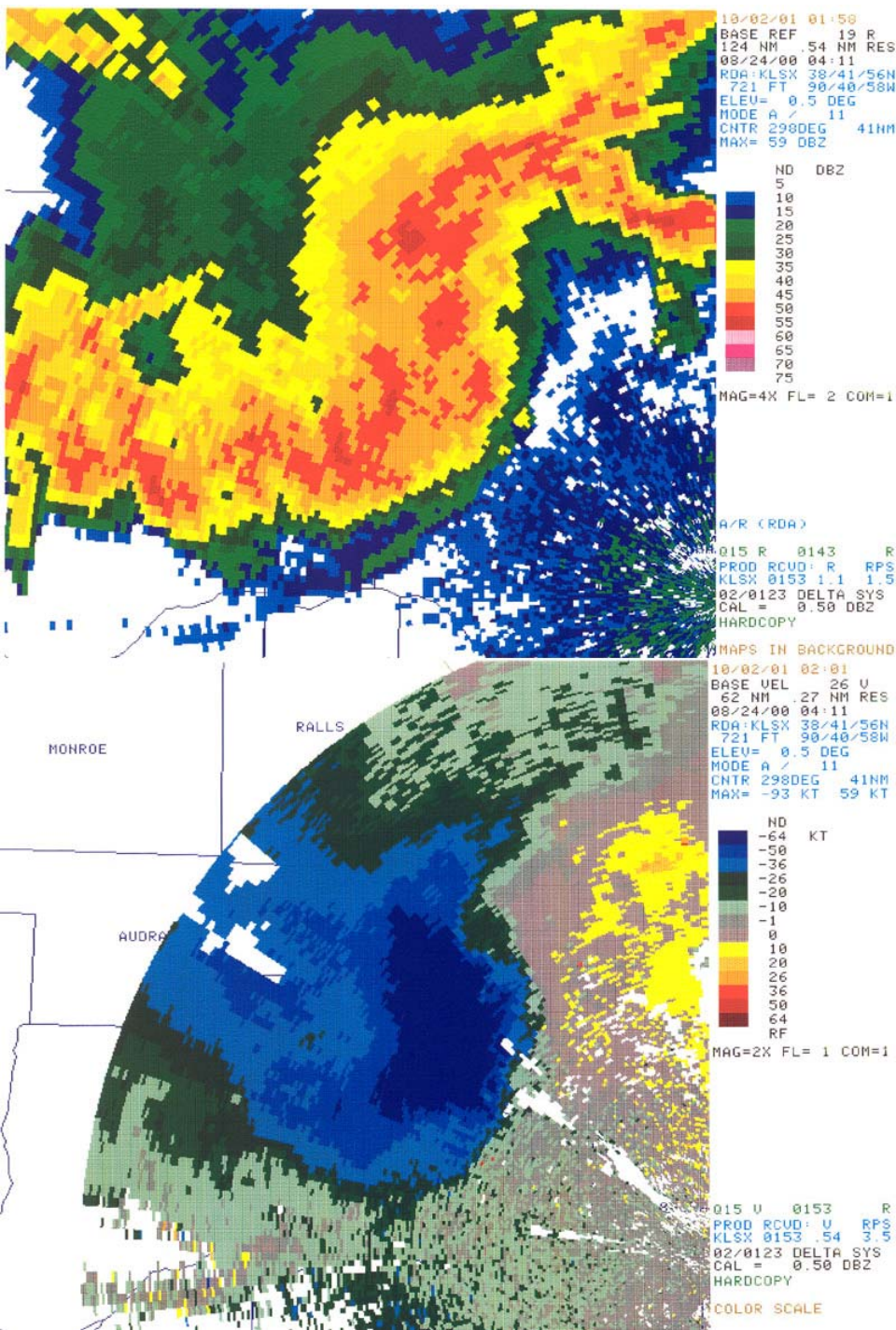
Later at 0411Z, 0.5 degree reflectivity & base velocity images depict a large, mature bow echo with an area of strong inbound winds (>64 kts) at about 4000 ft altitude NW of KLSX.

Damage Pics from Storm Survey done by Ron P. & Eric L. across Warren & Montgomery Counties NW of KLSX

Damage to roof (sheet metal) of school in Wright City

Tree damage near Bellflower in Montgomery County

Tree damage near a church in Montgomery County

Machine shed blown down east of Bellflower

Small house trailer blown over east of Middletown

Case Example #3 – May 27, 2000
(moderate instability & moderate shear)
MARC tracks & wind damage (W)
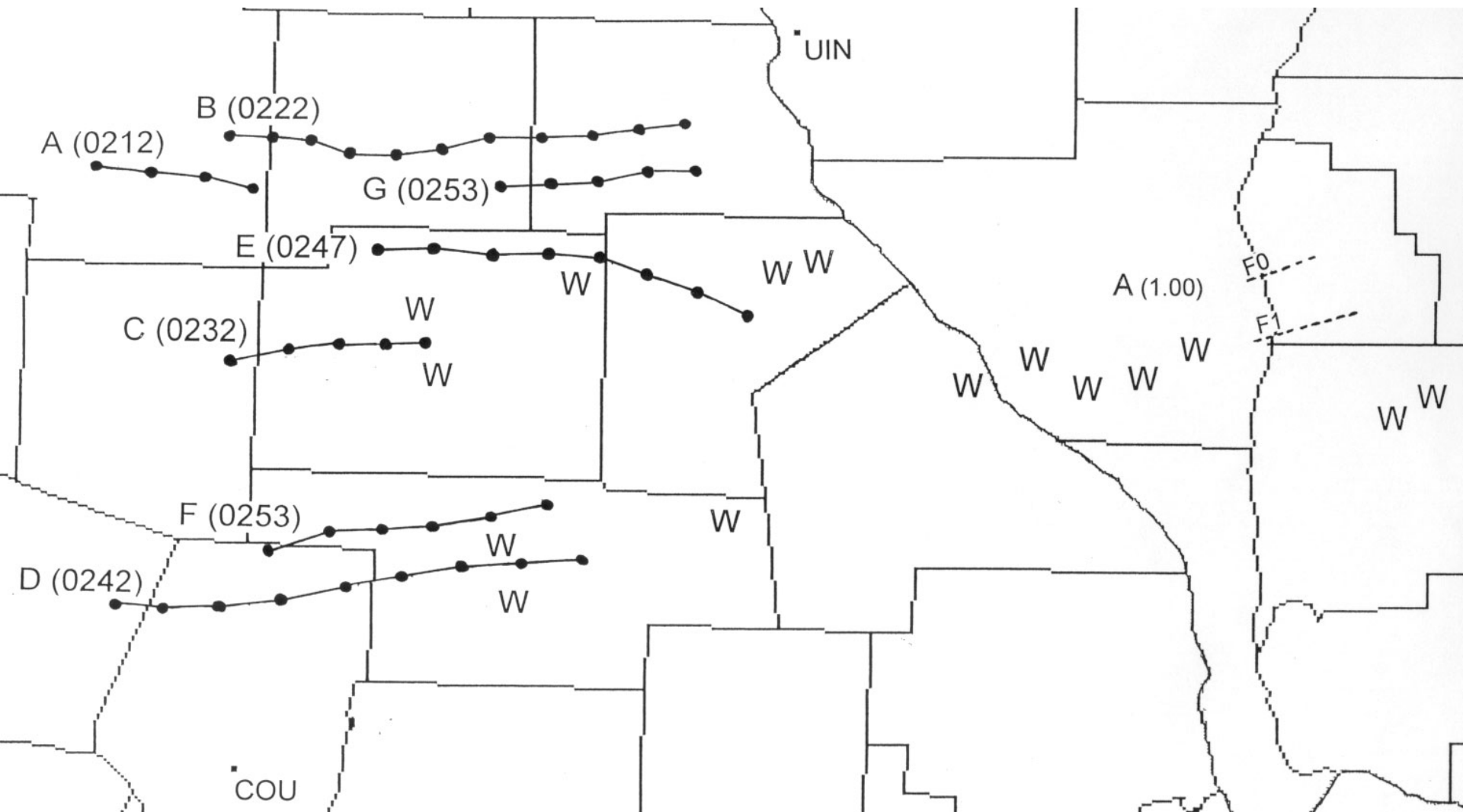
0303 UTC Reflectivity/SRM Velocity images at 1.5 ° depict 2 MARC signatures (D,E)
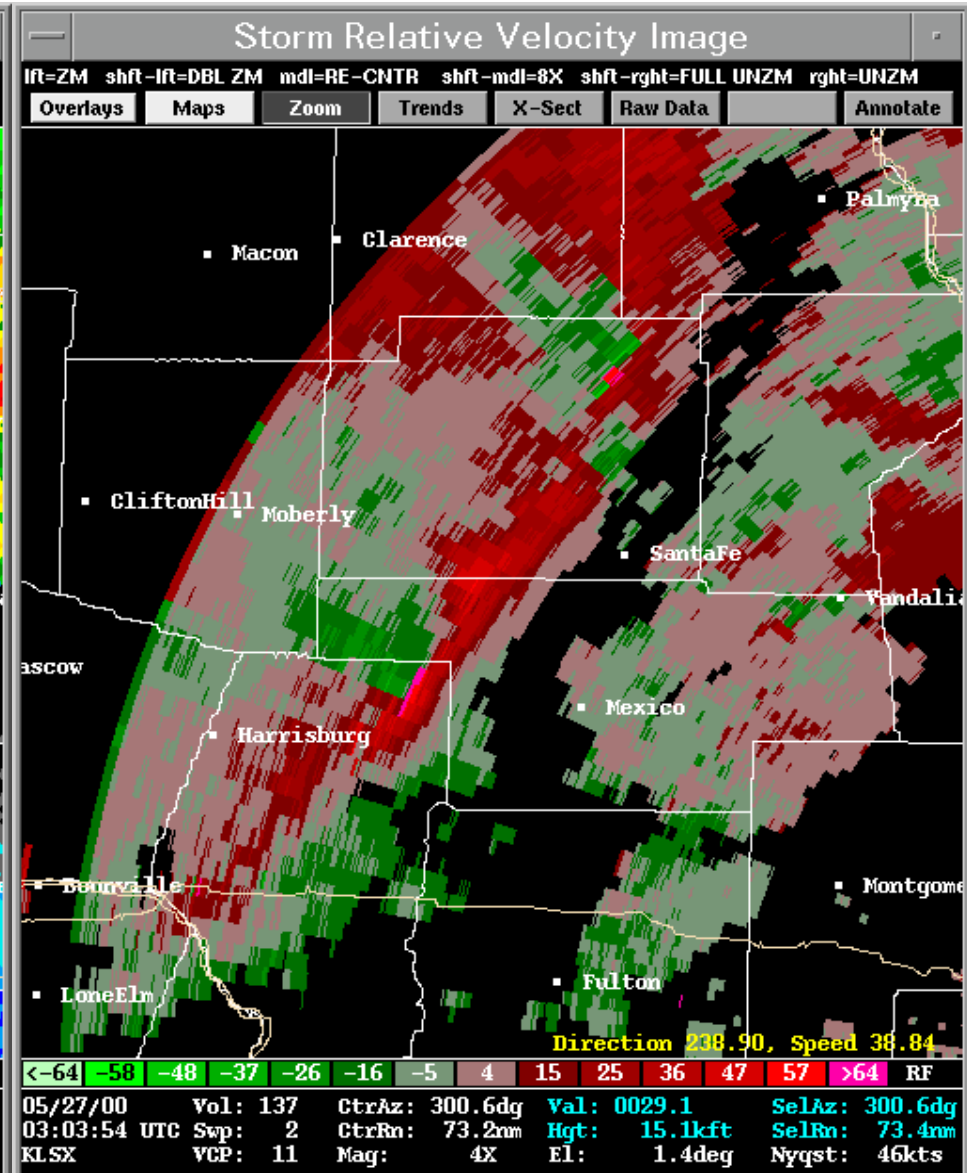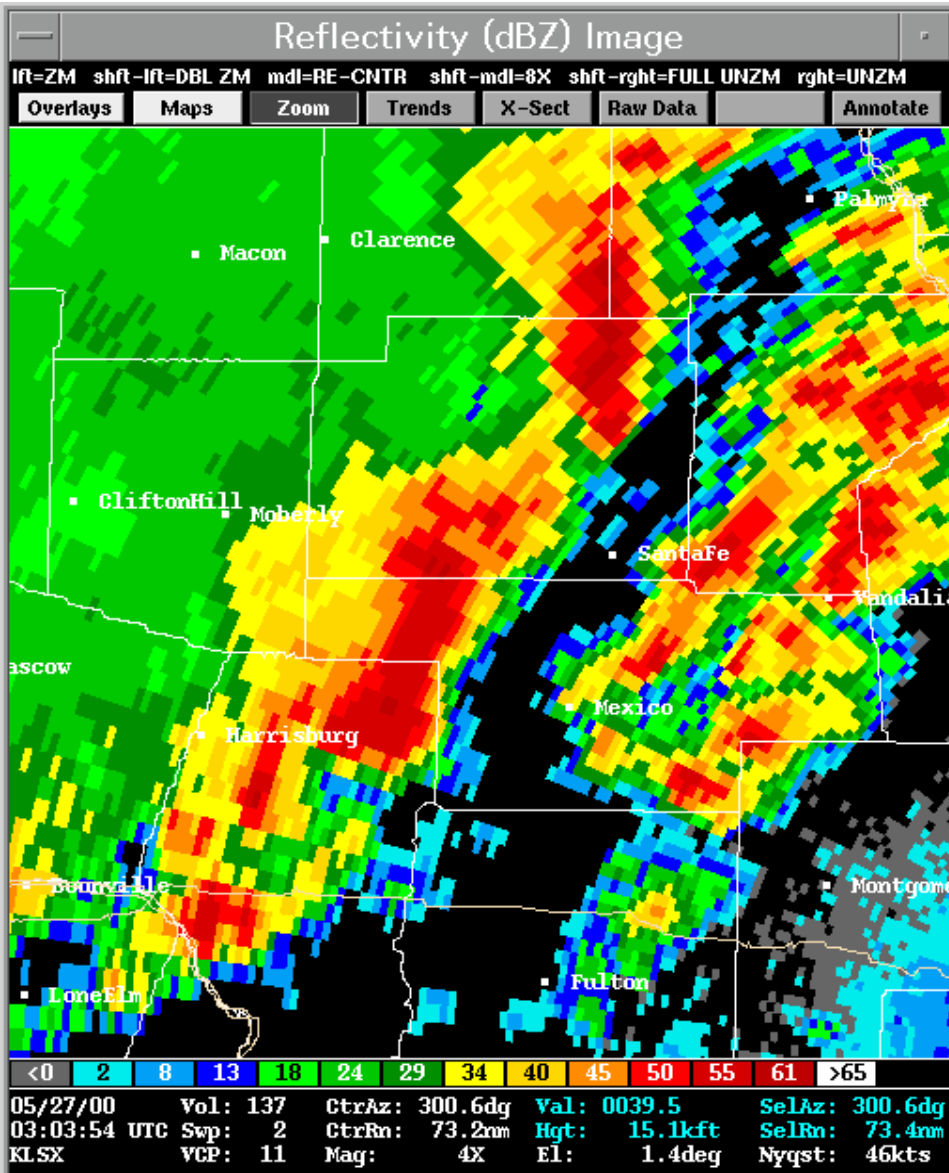
0308 UTC Reflectivity/SRM Velocity images at 0.5°
(Lets cut a x-section through MARC signature D)
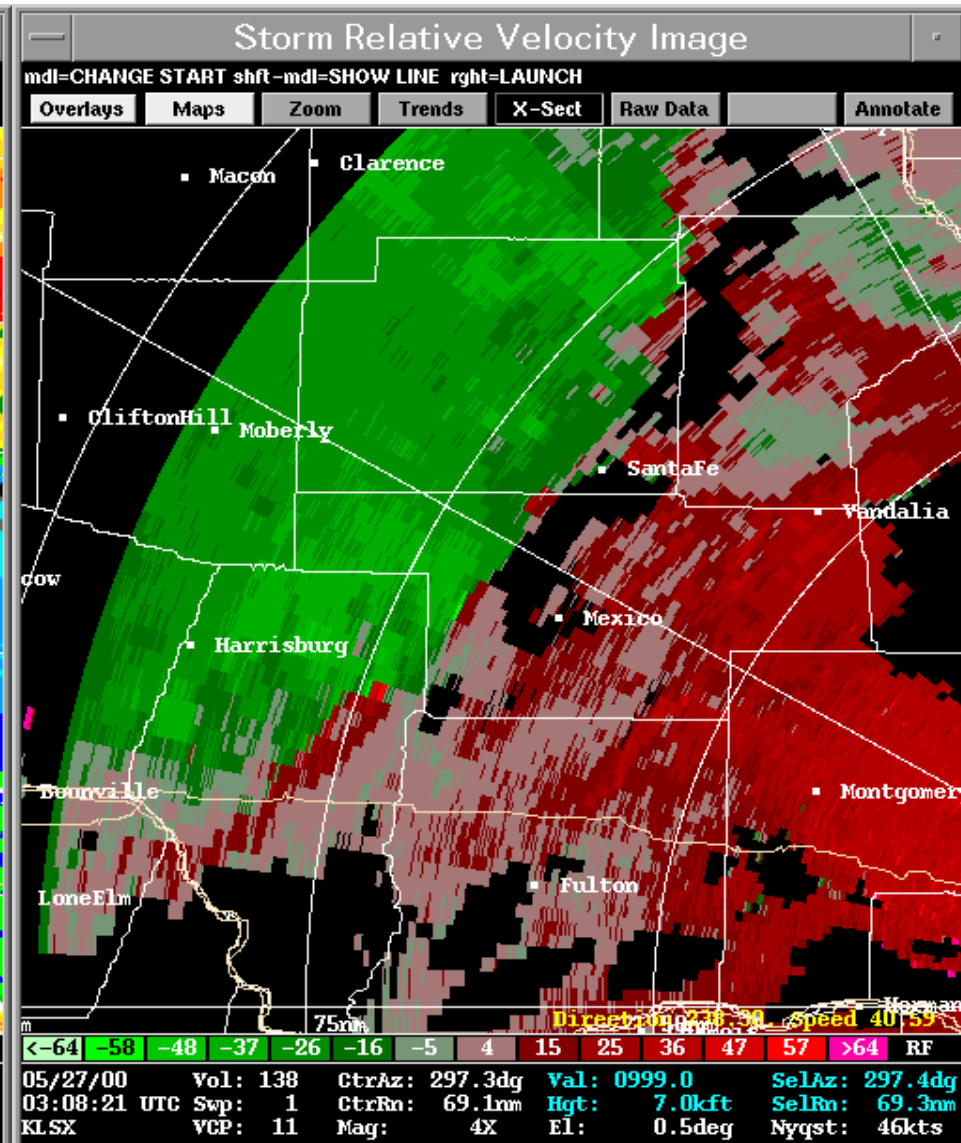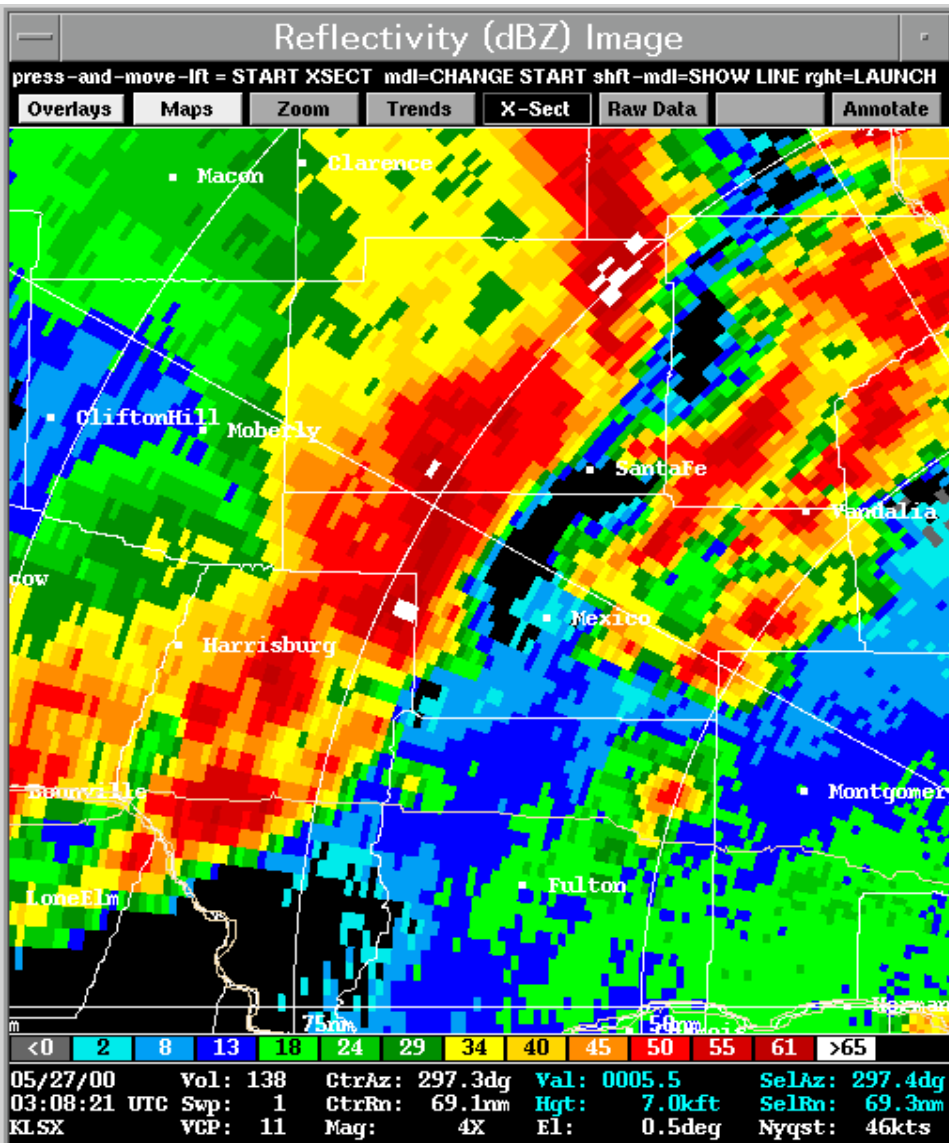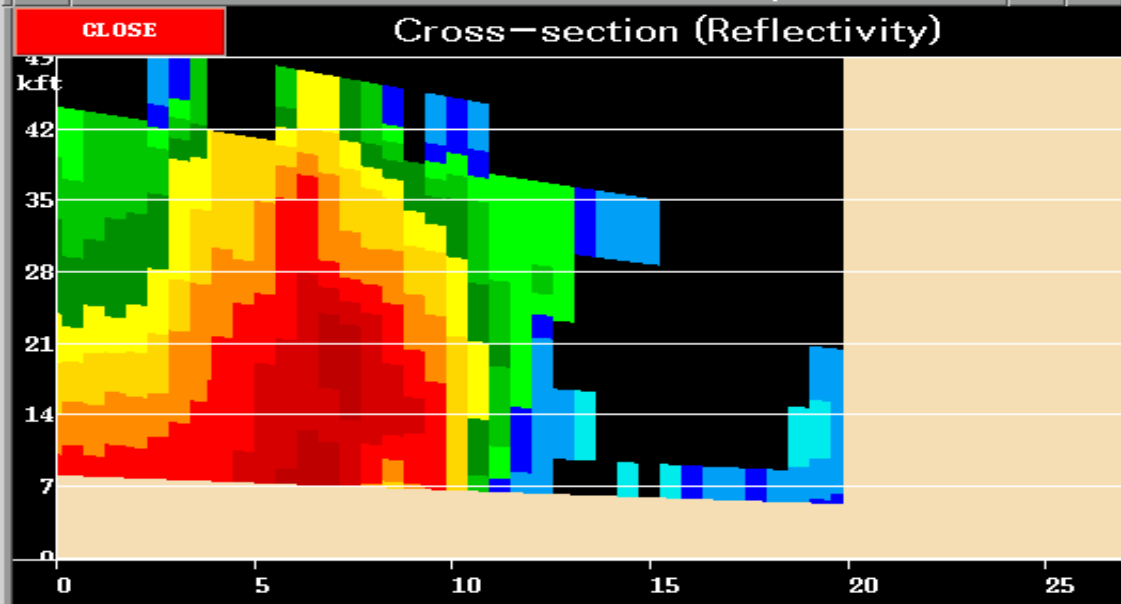
Reflectivity &Velocity X-Section at 0308Z depicting MARC & top of outflow (gust front) surging ahead of convective towers
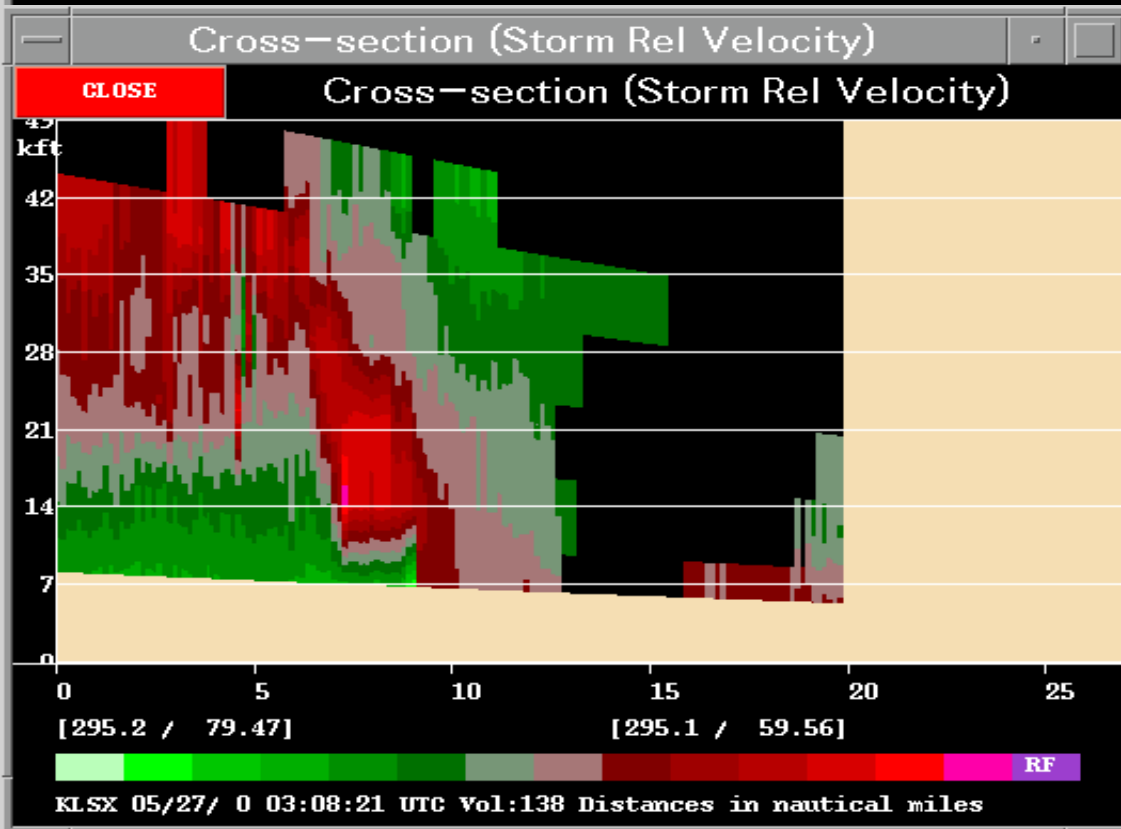
1.5° Reflectivity/SRM Velocity images at 0314 UTC - blue arrows point to 3 MARC signatures (D,E,F); Lets cut another x-section through D
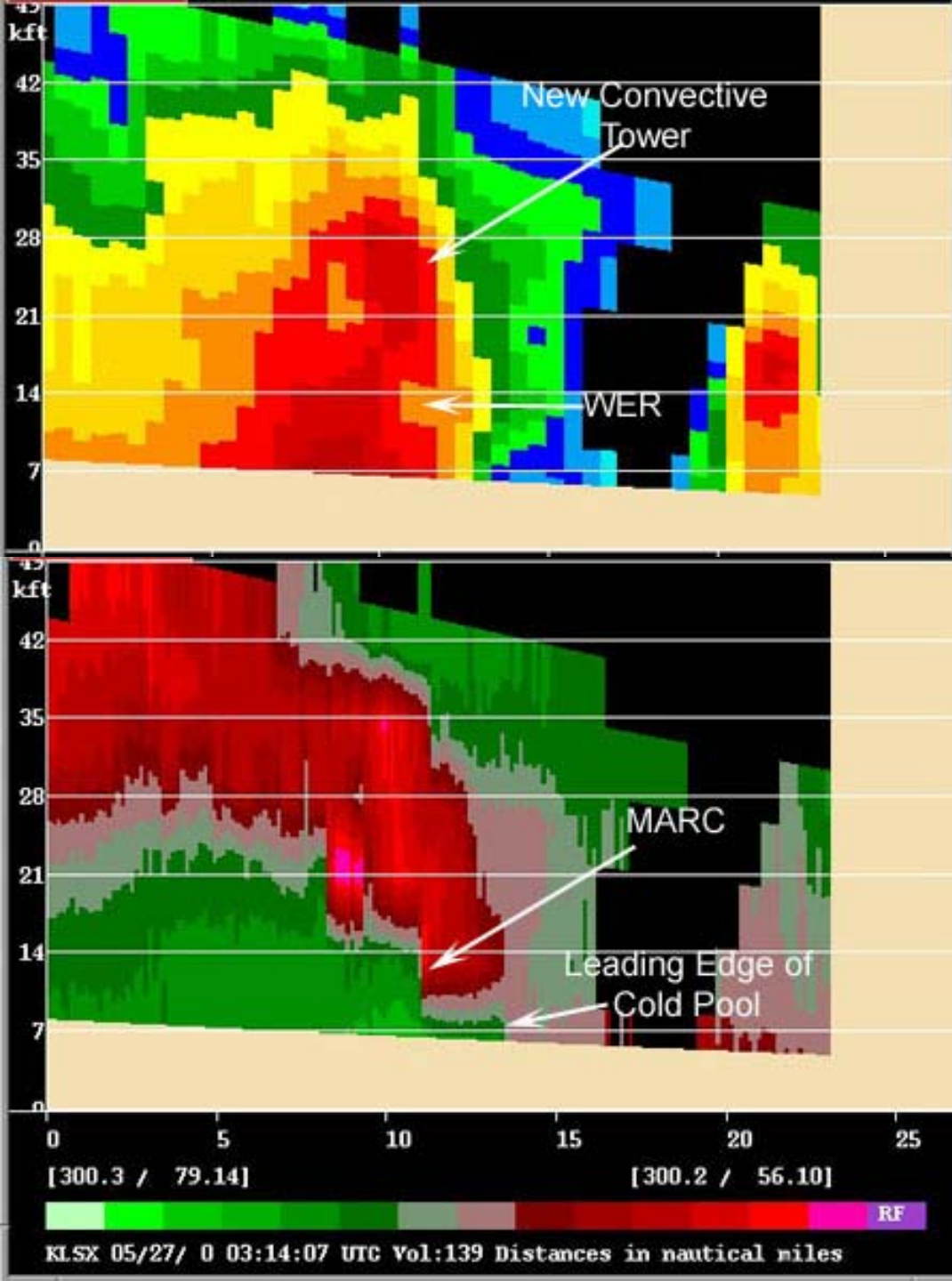
Reflectivity & Velocity X-Sections at 0314 UTC depict top of surging outflow (gust front) around 7 kft, MARC (10-15kft) near WER, & local outbound velocity max embedded within FTR flow around 21 kft

Time-height Section of MARC Signature "D"

Mid-Altitude Radial Convergence

26 May 2000: Magnitudes in (m/s)

Height (km)

Values in m s^{-1}
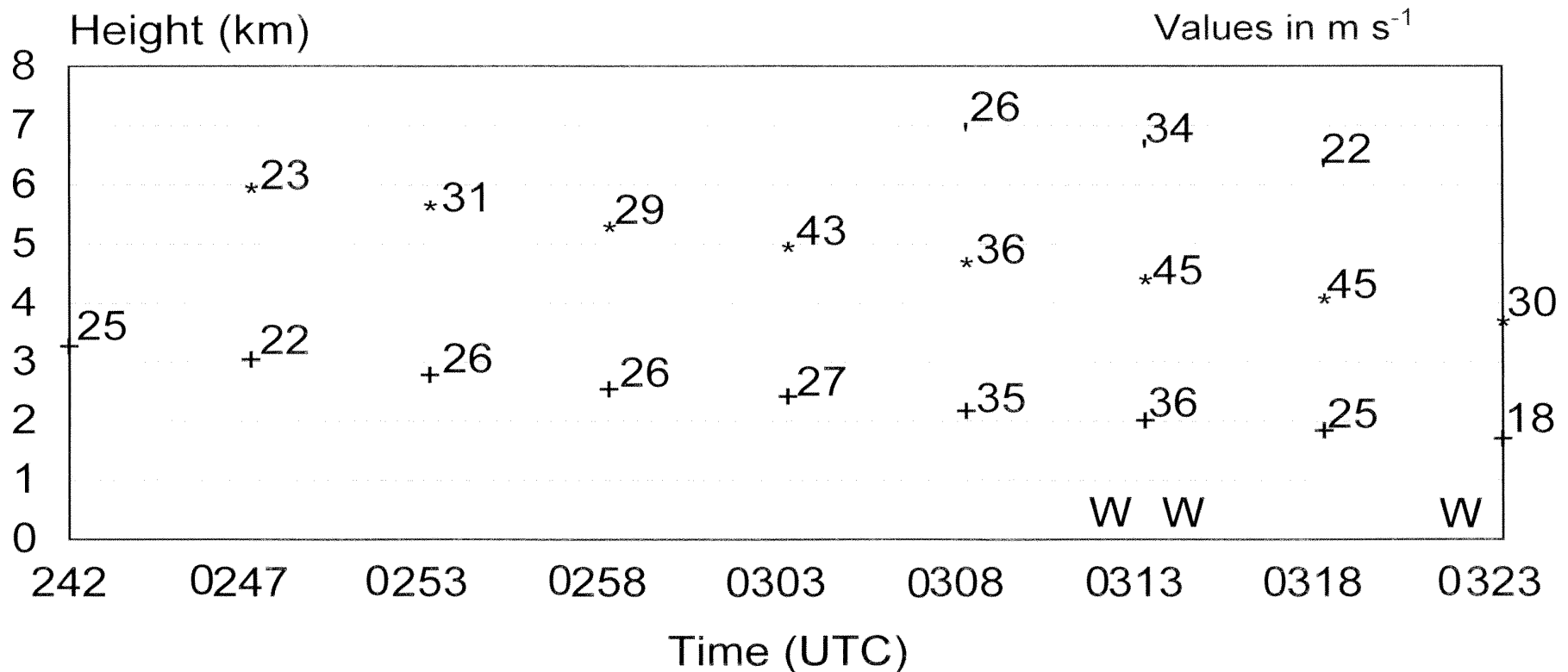
| + 0.4 degrees | * 1.4 degrees | ' 2.4 degrees |

Time (UTC)

Trace D

Summary & Key Findings

- The MARC velocity signature (>= 25 m/s or 50 kt) provided average lead times of almost 20 minutes prior to the first report of damaging winds.
  - often identified before the development of a well defined bow echo, or strong vortices (mesocyclone, line-end vortex)

- MARC usually identified at a height between 4-5 km (13 kft-16.5kft) along the forward flank of the convective line (in or just downwind of the high reflectivity cores within the line).

- Since it is a mid-level signature it can be detected as far as 120 nm from the radar using the lowest elevation slice.

- The MARC velocity signature has been observed more frequently with a nearly solid linear convective line compared to discrete convective cells along the southern flank of an asymmetric MCS.

Summary & Key Findings (cont.)

- Preliminary results indicate that the MARC signature is not as identifiable with nocturnal convection compared to convection occurring during the afternoon/evening hours (weaker magnitudes & shorter lead times with nocturnal cases examined so far).

- Importance of the viewing angle:
  -MARC will be underestimated when the convective line is not orthogonal (perpendicular) to the radial

- Even with a strong MARC signature, damaging winds are less likely if a deep (>=2 km), cool, stable surface based layer is present
  - this may occur if the convective line is well north of a stationary/warm front

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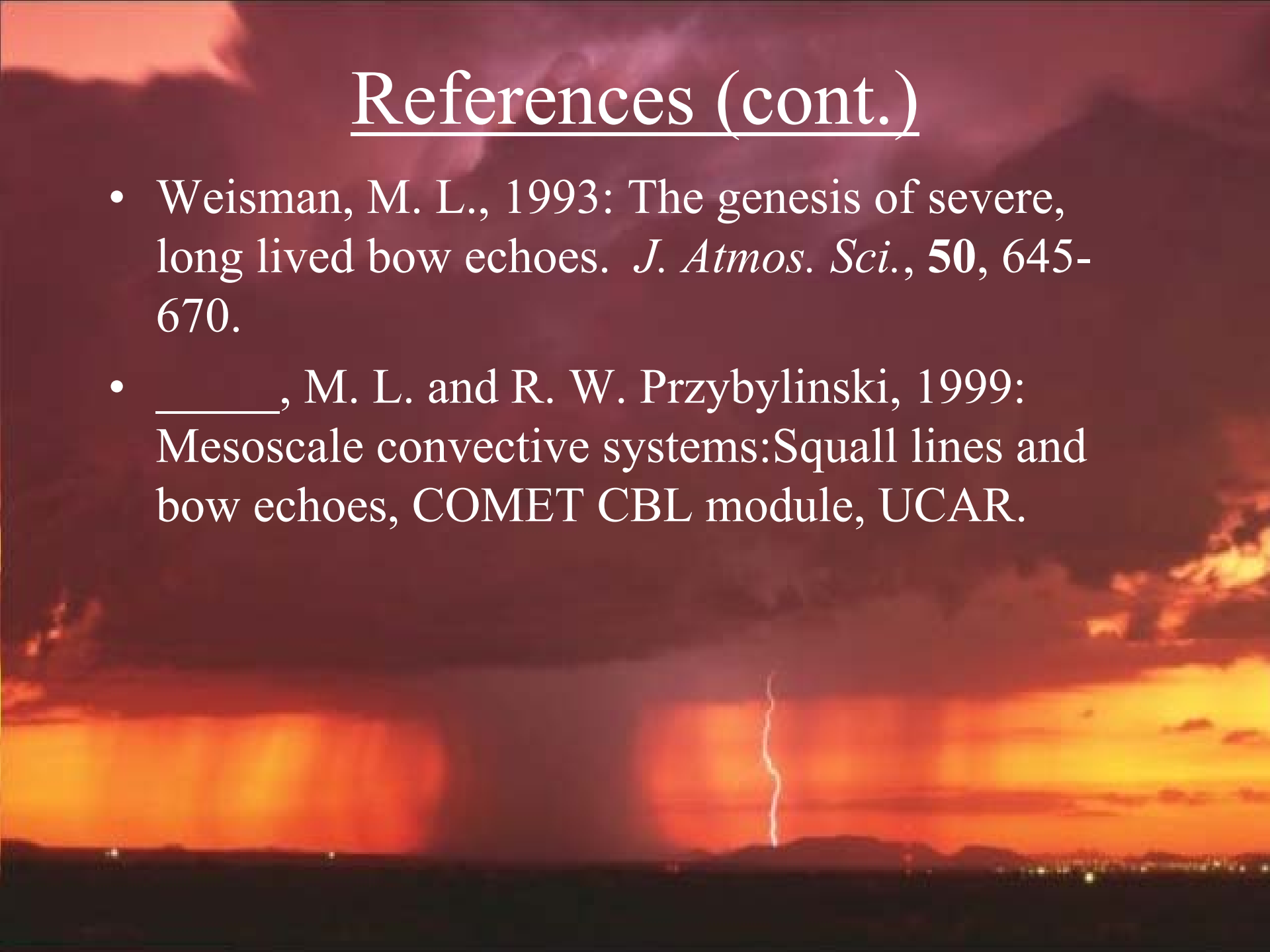
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newcomet.htm